ELECTROMYOGRAPHY OF MASTICATORY MUSCLES DURING ISOMETRIC CONTRACTIONS IN THREE MANDIBULAR REGISTRATION POSITIONS

THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF PREVENTIVE DENTAL SCIENCE

WINNIPEG, MANITOBA

BY

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ABSTRACT

This study examined the electrical activity of masticatory muscles during full (100%) and partial (10%) clenching in three mandibular registration positions (Retruded Contact Position, RCP; Intercuspal Position, IP; and Muscular Position, MP). Records were made with and without standardization of the distribution of dental contact. Three groups of subjects with different ranges of anteroposterior positioning of the condyles were studied (control group, class II division 2 group, and dual bite group). The amplitude of the linear envelope signal (EMG) from three bilateral muscles was recorded (masseter, anterior temporal, and posterior temporal). Data was analyzed utilizing a Mixed Analysis of Variance.

The results indicate that:

A. The main occlusal determinant of the ability for humans to deliver maximal masseter isometric muscle contraction is the uniform distribution of tooth contact. If the dentition takes the major role of stabilizing the mandible, e.g., there is good intercuspation, the masseter muscle can exert maximal isometric contractions. If the stability is not provided by the dentition, e.g., there is a premature contact, the jaw muscles and/or joints and/or ligaments should stabilize the mandible. The receptors monitoring stability seem to be variously

located and integrated to determine the presence or lack of stability.

B. The RCP does not seem to be an ideal position for intercuspation. If the relationship of the masticatory muscles is analyzed by the use of a ratio which is assumed to represent the interaction between biting and positioning muscles, i.e., masseter to posterior temporal muscle ratio, the RCP showed the lowest ratio. This is interpreted to mean that in the RCP the masticatory apparatus requires more positioning muscle activity (posterior temporal muscle), and limits biting muscle activity (masseter muscle).

C. Small changes in jaw position from IP to MP do not affect significantly the muscular behaviour when standardizing the distribution of occlusal contact.

D. Class II division 2 subjects showed the highest masseter muscle activity during full clenching and showed hyperactivity of the posterior and anterior temporal muscles during partial clenching in IP.

E. The dual bite group had the most significant reduction in the masseter muscle activity during clenching in the RCP.

To my family and the Great Colombia.

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This thesis is a result of contributions of various natures by several people. I would like to thank each one for their part in smoothing the path to the destination.

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REVIEW OF THE LITERATURE

A. Introduction

There are two major theories regarding the ideal location of the mandible when the teeth are in full intercuspation: the structuralistic and the functionalistic theories. Both concepts have the same treatment goal, namely to achieve harmonious relationships among the teeth, joints, and muscles.

Structuralistic theories state that the ideal position is in a given spatial relation, either dental or condylar or both (McCollum and Stuart, 1955; Huffman and Regenos, 1980; Lucia, 1983). Functionalistic theories conceive the ideal position as being neuromuscularly determined and not specified by the structural elements (Moyers, 1956, 1973; Silverman, 1957; Brill, 1959; Jankelson, 1973; Gelb, 1985).

Both theories have created conceptual and operational definitions of the sought-for ideal mandibular position. The conceptual component of each theory, e.g. centric relation (CR, McCollum and Stuart, 1955) for the structuralistic and muscular position (MP, Brill, 1959) for the functionalistic, lacks a quantifiable parameter and has been submerged in semantic confusion in spite of a number of attempts to rectify the terminology (Brill, 1959; Atwood, 1968; Gilboe, 1983). The operational component of the structuralistic theories, e.g. retruded contact position (RCP, Posselt, 1952), has gained temporary popularity among dental clinicians because of its practicality. The operational component of the functionalistic theories has defined the ideal position in three ways: unconsciously determined by the patient (swallowing reflex, Sheppard, 1959); consciously determined by the patient (first tooth contact position during jaw closure from rest position, Solberg, 1979); and operator guided position (operator guided first light tooth contact position, Arnold and Frumker, 1976).

The structuralists have set forward conflicting proposals regarding the ideal condylar position in maximal intercuspation. Early structuralists, e.g. gnathologists, based the position on the arrow point tracing which Gysi (Posselt, 1952) utilized in making full dentures, and proposed the "uppermost, rearmost, and midmost" as the ideal position of the mandibular condyles in maximal intercuspation (McCollum and Stuart, 1955). An emerging preference for the uppermost, foremost position is expressed by Celenza and Nasedkin (1978). Graham et al (1982) suggested a change in the definition of the ideal position from "the most retruded..." to "... the most anterior, superior physiological position of the condyles against the slope of the eminentia." Weinberg (1979) has suggested that the definition of the ideal condylar position should be expanded to include information obtained from temporomandibular joint (TMJ) radiographs or tomograms. He claimed that the ideal condylar position should have bilateral symmetry of the joint spaces with each condyle centrally located in the superior portion of the glenoid fossa. Others refuted this idea (Bush, 1982; Blaschke, 1982). McCollum and Stuart (1955), Roth (1972), and Lucia (1979, 1983) had as their treatment goal mandibular condyles in the "uppermost, rearmost, and midmost" position (i.e., retruded contact position (RCP), Posselt, 1952). Dawson (1974, 1985), Celenza and Nasedkin (1978), and Williamson (1985) proposed the uppermost and foremost position.

Structuralists still dispute whether the ideal position is or is not precise and reproducible. McCollum and Stuart (1955) believed that the ideal condylar position can be precise and reproducible. Celenza (1973) maintained that the most reproducible position and the ideal seem to be different positions. That there may be a range of acceptable positions has been suggested by Moss (1975) and Celenza (1978).

Since controversy still exists in defining jaw relationships, which is in part conceptual and in part semantic, the author prefaces this research report with a compendium of jaw position terminology.

B. Terminology

The jaw position with the teeth in maximal intercuspation could be described by the relationships within the joints, or between the teeth, and the muscles. The terms retruded contact position, intercuspal position, and muscular position have been selected to categorize a group of definitions used in the dental literature and will be the terms used in this thesis.

Retruded contact position, RCP, (Posselt, 1952) may be defined as that horizontal dental contact position of the mandible when further posterior displacement by an external force is restricted by the lateral ligaments (Posselt, 1952; Ingervall, 1968; McMillen, 1972), and/or the lateral pterygoid muscles (Boucher, 1961), and/or the disc (Saizar, 1971; El Mahady, 1971; Gilboe, 1983).

Synonyms of RCP are:

hinge axis centric (McCollum, 1927)

ligamentous position (Posselt, 1952)

centric position (McCollum and Stuart, 1955)

centric jaw relation (Beyron, 1969)

terminal hinge position (Beyron, 1969)

uppermost-rearmost-midmost position (Huffman and Regenos, 1980)

hinge position (Lucia, 1983)

Intercuspal position, IP, (Posselt, 1952) may be defined as that horizontal position of the mandible in which the cusps of the mandibular and maxillary teeth intercuspate maximally.

Synonyms of IP are:

median occlusal position (Sicher, 1956)

cuspal position (Brill, 1959)

centric occlusion (Glickman, et al. 1969)

habitual occlusion (Glickman, et al. 1969)

functional occlusion (Ågerberg, 1974)

maximum intercuspation (Buxbaum, et al. 1982)

working position (Møller, 1981)

Muscular position, MP, (Brill, 1959) may be defined as that horizontal dental contact position of the mandible obtained by symmetrical muscular contraction.

Synonyms of MP are:

rest centric (Mann and Pankey, 1963)

ideal occlusal position (Moyers, 1973)

centric relation (Celenza, 1978)

neuromuscular centric (Solberg, 1979)

ideal structural position (Møller, 1981) muscle contact position (Mohamed and Christensen, 1985)

On reviewing the basic terminology regarding mandibular registration positions, one thing is clear: the same terms mean different things to different people. Therefore, as an inevitable result, confusion persists. To surmount this, there is a need for operational rather than conceptual definitions. The operational definitions should be of practical value and in harmony with the biology of the masticatory apparatus.

C. Biomechanical Conceptualization of the Jaws and the TMJs in Maximal Intercuspation.

1. The Concept of Stability

Dentists trying to express biomechanically the factors controlling the relationships of the jaws and the TMJs in the ideal jaw relationship have invoked the concept of stability. The terminology used to express this biomechanical requirement of positioning the jaws in the intercuspal position includes concepts of "binding" (Saizar, 1971), "bracing" (Dawson, 1974), "stabilizing" (Storey, 1981; Ramfjord and Ash, 1983), and "equilibrium" (Gelb, 1979; Gilboe, 1983).

2. Components of Mandibular Stability in IP

The assertion of mandibular stability implies control by either of two components: passive and active. The structures assumed to provide the passive stabilizing component are: TMJ bones (Saizar, 1967; Dawson, 1974; Gilboe, 1983), TMJ ligaments (Saizar, 1967; Dawson, 1974; Gilboe, 1983), TMJ disc (Saizar, 1967; El Mahady, 1971; Gilboe, 1983), and teeth (Moffet, 1966; Celenza, 1973). The structure assumed to provide the active stabilizing component is the masticatory musculature (Saizar, 1967; McNamara, 1973; Dawson, 1974; Gilboe, 1983).

Theoretically, the masticatory musculature could contribute to mandibular stability by the relative contribution of the different fiber types in the muscle and by the geometrical assembly of the musculature.

Human muscle contains fibers with varying anatomical, physiological, and histochemical properties (Rose and Rothstein, 1982). Enzyme histochemical investigation has shown that the human masticatory muscles have at least four types of fibers: type I, II-A, II-B, and II-C (Eriksson et al, 1981). Type I fibers are slow-twitch, glycogen-poor, and high in aerobic enzymes and mitochondrial density. They are resistant to fatigue and well-suited to prolonged activity such as postural maintenance (Eriksson et al, 1981). A particularly high proportion of type I fibers is normally found in human muscles which have an almost exclusively postural function (Edstrom and Nystrom, 1969; Johnson et al 1973; Gollnick et al 1974).

According to Eriksson et al (1981, 1982), and Eriksson and Thornell (1983), the percentage of type I fiber in the overall muscle fiber cross-sectional area of the masticatory muscles ranged as follows:

masseter from 70.2% to 87.9%

medial pterygoid from 52.3% to 78.6%

digastric from 24% in the anterior belly to 38% in the posterior belly

temporal from 52% in the anterior part and 89.9% occurring in the posterior part

lateral pterygoid in both heads, 81.3%

On the evidence provided by Eriksson et al (1981, 1982) and Eriksson and Thornell (1983), the predominance of type I fibers in both heads of the lateral pterygoid and the deep portion of the posterior temporal muscles may indicate a capacity for endurance during continuous work in accordance with the stabilizing role attributed to these muscles by DuBrul (1980). The high proportion of type I fibers in some areas of the masseter and medial pterygoid muscles may be explained by the expected endurance during continuous work of the masticatory muscles.

The geometrical assembly of the masticatory muscles is thought to contribute to the stabilization of the jaws. The special fiber orientation of both the posterior temporal and the upper heads of the lateral pterygoid muscles seem to ensure stability of the joint while the powerful biting muscles act, the masseter-medial pterygoid sling (DuBrul, 1980). The stabilizing role of the lateral pterygoid muscle has been suggested by Carlsöö (1956), Honée (1972), and Molin (1973). That the superior head specifically contributes to the stability of the TMJ has been suggested by McNamara (1973), Mahan et al (1983), Gibbs et al (1984), and Juniper (1984). Williamson (1985) maintains that the superior head of the lateral pterygoid muscle and the temporal muscle are responsible for the seating of the condyles bilaterally in a stable position. Ideas that are emerging from the work of Smith (1984) suggest that the division of the masticatory adductor muscles into biters and stabilizers can be verified in light of the moment arm length of the muscles. The masseter and medial pterygoid muscles have the longest moment arms, which allow them to generate higher biting forces. The posterior temporal and the lateral pterygoid muscles have the shortest moment arms, which permit them to work as joint stabilizers.

On the evidence presented by the histochemical and geometrical analysis of the masticatory musculature, it could be concluded that it is feasible to divide the muscles into biters and stabilizers.

D. Muscular Behaviour in Different Occlusal Positions (RCP and IP)

Although relationships between jaw position and jaw muscle function have been reported, there are very few investigations showing the quantitative relationship between jaw position in dental contact and muscular activity. Some investigators have attempted to compare the muscle activity during clenching while varying the sagittal position of the mandible from RCP to IP (see Table I and Table II), (Pruzansky, 1960; Ingervall, 1979; Kohno et al 1981; Buxbaum et al 1982; Mahan et al 1983; Gibbs et al 1984; Ramfjord, 1984). None of these investigators has standardized the biting force, and only Ramfjord (1984) has standardized the amount of dental contact. Since Bakke and Møller (1980) have shown that the exertion of maximal elevator activity during biting depends on the number and distribution of occlusal contacts, any conclusions from these studies would be hazardous. The aforementioned studies were undertaken to find the ideal condylar position in maximal intercuspation and to define the ideal occlusal position in terms of muscular

TABLE I

Muscular activity during maximal clenching in the RCP versus the IP. (+)

Author	Muscle	Position RCP%	Position IP%
1. Pruzansky (1960) 1 subject (Normal occlusion)	Anterior Temporal (SE)	90%	70%
	Posterior Temporal (SE)	90%	80%
	Masseter (SE)	0%	100%
2. Ingervall (1979) 12 subjects (Dual bites)	Anterior Temporal (NE)	100%	79%
	Posterior Temporal (SE)	69%	27%
	Masseter (SE)	26%	64%
3. Kohno et al (1981) 3 subjects	Anterior Temporal (SE)	30%	80%
	Posterior Temporal (SE)	100%	80%
	Masseter (SE)	6%	100%
4. Buxbaum et al (1982) 12 subjects	Anterior Temporal (SE)	100%	55%
	Masseter (SE)	60%	40%
5. Mahan et al (1983) 9 subjects (2 with TMJ disorders)	Inferior Lateral Pterygoid (NE)	0%	35%
	Superior Lateral Pterygoid (NE)	100%	80%
6. Gibbs et al (1984) 11 subjects (2 with TMJ disorders)	Anterior Temporal (SE)	55%	100%
	Masseter (SE)	10%	100%
	Anterior Digastric (SE)	40%	30%
	Superior Lateral Pterygoid (NE)	90%	70%
	Inferior Lateral Pterygoid (NE)	0%	40%
	Medial Pterygoid (NE)	0%	70%

(+) No standardization of the distribution of dental contact nor biting force was attempted.
Percentages of muscle activity compared to maximal were interpolated from data presented by the respective authors.

SE Surface-electromyography

NE Needle electromyography.

TABLE II

Muscular activity during maximal clenching in the RCP versus the IP. (+)

Author	Muscle	RCP	IP
Ramfjord (1984) 1 subject	Masseter (SE)(+)	50%	100%

(+) The distribution of dental contact was standardized by a full coverage splint.
Percentages of muscular activity compared to maximal were interpolated from data presented by the author.

SE: surface electromyography.

behaviour. The terminology used to define the ideal occlusal position as it relates to muscular behaviour was: balanced and unstrained muscle activity (Moyers, 1956), harmonious muscle activity (Ingervall, 1979; Ramfjord, 1984), minimal muscular activity (Buxbaum, 1982), and maximal muscle activity (Gibbs et al 1984; Ramfjord, 1984). Buxbaum et al (1982) and Ramfjord (1984) agreed that the RCP is not an optimal position, but arrived at this conclusion from diametrically opposed interpretation of the data.

Buxbaum (1982) contends that muscle hyperactivity in the RCP may explain the changes that led to the reoccurrence of the RCP-IP slide in rehabilitations that were carried out according to gnathological principles by Celenza (1973), (see Table I). Conversely, Ramfjord (1984) maintains that the jaw appears to be naturally protected from greater force in the RCP as evidenced by the dramatic decrease in the activity of the masseter muscle (see Table II). There have been no investigations to account for the muscle hyper- or hypoactivity during clenching in the RCP.

The differences in the findings of these studies could be related to:

1. the different muscles or regions of the muscles monitored.
2. the absence of standardization of the amount and even distribution of dental contact between the RCP and IP.

The usual presence of unilateral unbalanced dental contact in the RCP might account for the completely different muscular behaviour.

3. the absence of standardization of the amount of biting force.

4. failure to group subjects according to the distance between RCP and IP.

E. Conclusions Drawn from the Review of the Literature

1. In spite of a profusion of articles written in an attempt to unravel the confusion regarding jaw relationships in maximal dental contact, controversies still exist. The controversy is in part conceptual and in part semantic. There is a need for operational rather than conceptual definitions. The operational definitions will eliminate the semantic confusion.

2. The assertion of mandibular stability in maximal intercuspation seems to be controlled by two components: passive and active. On the evidence presented by the histochemical and geometrical analysis of the musculature it could be concluded that it is feasible to divide the muscles into biting and stabilizing components.

3. The anatomic and functional determinants of an ideal position

of the mandible in maximal intercuspation are unknown.

STATEMENT OF THE PROBLEM

The present study deals with the electrical activity of masticatory muscles during full (100%) and partial (10%) isometric muscle contraction (clenching) in three mandibular bite registration positions (RCP, IP, and MP) without and with standardization of the distribution of dental contact.

The rationale of this study was to examine the electromyographic (EMG) activity of the masseter, the anterior temporal, and the posterior temporal muscles in subjects grouped according to the distance between the RCP and IP.

An attempt was made:

A. to evaluate the changes in electrical activity of masticatory muscles during clenching in the RCP and IP without standardizing the distribution of dental contact.

B. to evaluate the changes in electrical activity of masticatory muscles during clenching in the RCP, IP, and MP while standardizing the distribution of dental contact.

C. to evaluate the changes of electrical activity between sample groups (control, class II division 2 angle malocclusion, and dual bite).

D. to correlate the changes of electrical activity with variations in the distribution of dental contact and with changes in the anteroposterior position of the mandible.

METHODS AND MATERIALS

A. Sample

The study was carried out on 37 subjects subdivided as follows:

Group I (control) consisted of twelve subjects with normal occlusion, i.e. class I molar relation, with a mean overbite of 2.33 mm and a mean overjet of 2.12 mm. These normal subjects were free of temporomandibular disorders (TMD) and had a mean RCP-IP distance of 0.65 mm with a Sd of 0.19 mm. All of them had a full permanent dentition exclusive of third molars. Eight were females and four were males (see Figure 1).

Group II was made up of fourteen class II division 2 Angle malocclusion subjects with a mean overbite of 6.71 mm and a mean overjet of 1.70 mm. The class II division 2 subjects were free of TMD and had a mean RCP-IP distance of 0.36 mm with a Sd of 0.20 mm. All of them were in the permanent dentition stage. Eight were females and six were males (see Figure 1).

Group III contained eleven dual bite* subjects with a mean overbite of 1.77 mm and a mean overjet of 3.50 mm. One of the dual bite subjects had symptoms of TMD. The mean RCP-IP distance was 3.86 mm with a Sd of 1.74 mm. All of them had or were under orthodontic treatment. One subject was in the mixed dentition stage. Six were females and five were males (see Figure 1).

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* Dual bite: An occlusion with an abnormally long anteroposterior difference between the RCP and IP (Ingervall, 1979).

Figure 1: Sample description. Grouping of the subjects according to the distance between the RCP and IP in the sagittal plane. Diagram in the upper right hand based on Posselt (1962).

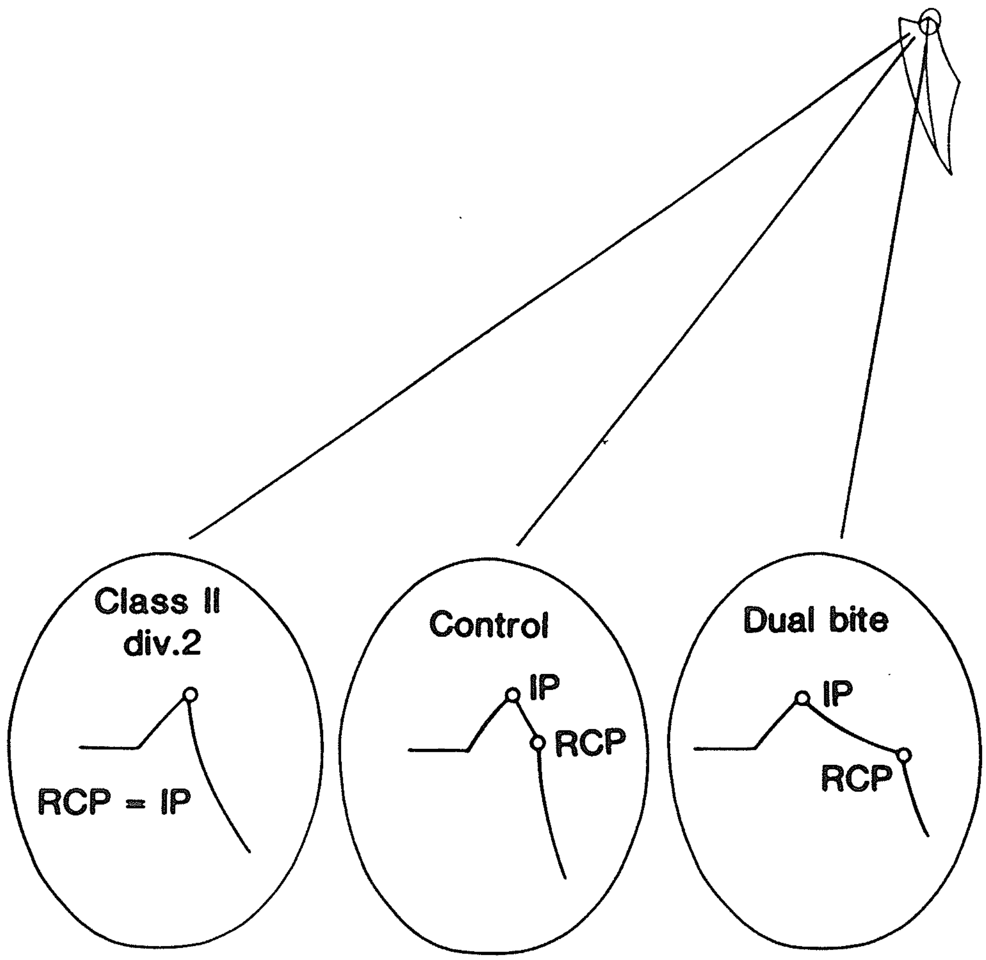

Figure 1

B. Equipment and Methodology

1. EMG Equipment

The following specifications adhere to the guidelines in terminology and methodology suggested by Winter (1983). A series 2,500 eight channel Honeywell apparatus (Model 1508) was utilized for all recordings. Six channels of raw or processed data from 3 bilateral muscles were recorded in this study. The processed signal (linear envelope) was used for quantification. The raw EMG signal was processed by means of full wave rectification and first order low pass filtering with a 3 db cut off frequency of 10 Hz to form a linear envelope. The linear envelope closely follows the amplitude of the peaks of the raw EMG and is a suitable method for demonstrating peak activity (Winter, 1983). The EMG signal was amplified at an overall voltage gain of 4000. The signal amplifier was designed and constructed by Mr. Arthur Quanbury in the electronic shop of the Biomedical Engineering Research Department of the Rehabilitation Centre for Children, Winnipeg. The input impedance of the amplifier was 20 megohms and the common mode impedance 10 megohms. The band width was from 22 hertz (Hz) to in excess of 2.3 KHz. The common mode rejection ratio extended from 80 to 100 db at 60 Hz. The sensitivity of the EMG apparatus ranged from 0.5 - 200 volts/cm. Bipolar silver/silver chloride surface electrodes

0.4 cm in diameter (Beckman Instruments, Inc. Schiller Park, IL 60176, Catalog No. 650950) were used in the study. Electrodes were connected to a pair of twisted conductors that were surrounded by a grounded shield.

2. Dental Registrations

Alginate impressions (Jeltrate - L.D. Caulk Company) of each patient were made and poured in stone (Die-Keen green - Columbus Dental, St. Louis Mo. 63188). Three mandibular registration positions were recorded prior to the experiment. The bite registrations were made using autopolymerizing acrylic (Orthojet Acrylics - Lan Dental Mfg. Co. Inc., Ill, 60647) after the technique of Hellsing et al (1983). For the registrations, all subjects were seated in a dental chair reclining 15 degrees from the upright position. The bite registration material was placed bilaterally on the occlusal surface from the second molar to the first bicuspid. Patients' saliva was used as a separating medium. The patients were asked to sustain the positions for about three minutes until the acrylic set.

a. Muscular Position Registration

The MP registration was made ensuring that the subjects were relaxed. A cotton roll was placed between the anterior teeth for 5 minutes prior to recording, to block out occlusal feedback (Dawson, 1985). The patient's head was placed between the chest and forearm of the operator. The operator's thumbs rested on the mandibular symphysis and his fingers rested along the lower border of the mandible bilaterally. Patients were asked to relax to enable the operator to hinge the mandible freely. When it appeared that relaxation had occurred (mandible arcing freely) the patient was asked to close the mandible slowly till the first point of dental contact was reached. This procedure was repeated several times until the patient consistently reproduced this position (see error study of MP registration). Then, autopolymerized acrylic was placed on the teeth and the patients were manipulated in the same way as in the preliminary session and asked to close to the first point of contact.

b. Intercuspal Position Registration

The IP registration was made by asking the patients to bite in their usual intercuspal position. In the dual bite group, since two occlusal positions can easily be utilized (Egermark-Eriksson et al 1979) two IP registrations were made if the subject reported their use during chewing. The most forward IP registration was used to specify the RCP-IP distance.

c. Retruded Contact Position Registration

The RCP registration was made with a manually applied force in the posterosuperior direction of 3.5 kg. As Ingervall et al (1971) recommended, the force used to retrude the mandible was standardized: a chinpoint spring calibrated to activate a signal light at 3.5 kg was used. The dorsal force was sustained throughout the registration period. Patients were asked to report whether the dental contact that they noted in a preliminary training session without registration material was the same as with the registration material. If there was any doubt, it was repeated till consistency existed between the preliminary and the actual registration.

3. Articulator Mounting and Buhnergraph Measurements

A semiadjustable, arcon-type articulator (Whip Mix, Model No. 8500; Whip Mix Corporation, Louisville, Kentucky 40217) was used for the mounting. Condylar positions in the three registration positions were compared using the Buhnergraph (Buhnergraph, Dental Items, Inc. Tipp City, Ohio) after the method of Long (1970) and Lundeen (1974).

A hinge-axis facebow (model 8614) was used to transfer the maxillary cast to the Whip Mix articulator. The mandibular cast was mounted with an IP record. The condylar posts of the mandibular frame of the articulator were replaced with a bar containing two pointed styli facing the right and left maxillary condylar housing elements (see Figure 2). Millimeter graph paper flags were attached to the maxillary condylar housing elements. Articulating paper was interposed between the styli and the paper flags and a registration point was recorded on each side for each registration position (RCP, IP, and MP). The angulation of the maxillary condylar housing elements was kept constant at 30 degrees for all of the experiments and the origin of the X and Y axes for measuring the RCP-IP and RCP-MP distance was placed on the RCP registration point bilaterally. The X axis had the same angulation as the condylar housing elements. A dissecting microscope (Olympus, Tokyo) at 25 times magnification was used to calculate the distances in the X and Y axes to the nearest tenth of a millimeter.

Figure 2: Buhnergraph method. Condylar positions in the three bite registrations were compared using the Buhnergraph method. Magnification insets demonstrate the right pointed stylus facing the right maxillary condylar housing element.

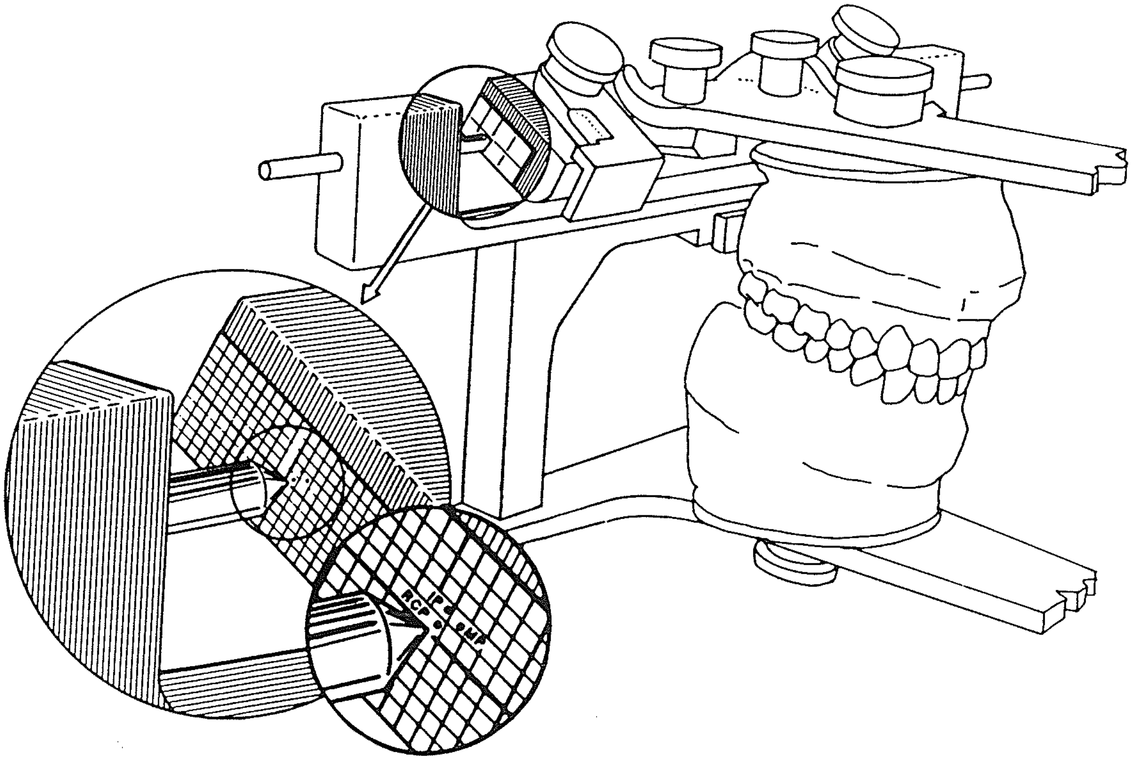

Figure 2

4. Electrode Placement and EMG Recording

The bilateral placement of the electrodes was standardized after the technique of Ahlgren et al (1973). A ground electrode was placed over the radial prominence on the right hand. For the standardization of electrode placement two templates with reference lines were designed (see Figure 3). The template containing the temporal reference line was placed between the superior insertion of the ear and the corner of the eye. The anterior temporal muscle electrode placement reference was at a point 3 cm behind the corner of the eye and 3 cm superior to the temporal reference line (see Figure 4). The posterior temporal muscle electrode reference was at a point 3 cm above the temporal reference line and 1 cm dorsal to the superior insertion of the ear (see Figure 4). The masseter muscle electrode reference was at a point 2 cm dorsal to the anterior border of the masseter and 3 cm inferior to Camper's line (see Figure 4). The two heads of the bipolar electrodes were oriented vertically half a cm above and below the reference points. Muscle boundaries were determined by palpation.

For the electrode placement, the skin was cleansed with alcohol and abraded at the electrode site with the sawcut end of a 9 mm diameter wooden dowel. The electrodes were filled with electrode paste (Beckman Instruments Inc. Schiller Park, IL 60176, Catalog No. 201210) and affixed with double-sided adhesive collars (Sensor Medics, Anaheim, CA, 92806, Catalog

Figure 3: Templates for electrode placement. Upper template contains the temporal reference line. Lower template contains the masseter reference line. The shown orientation is for the right side.

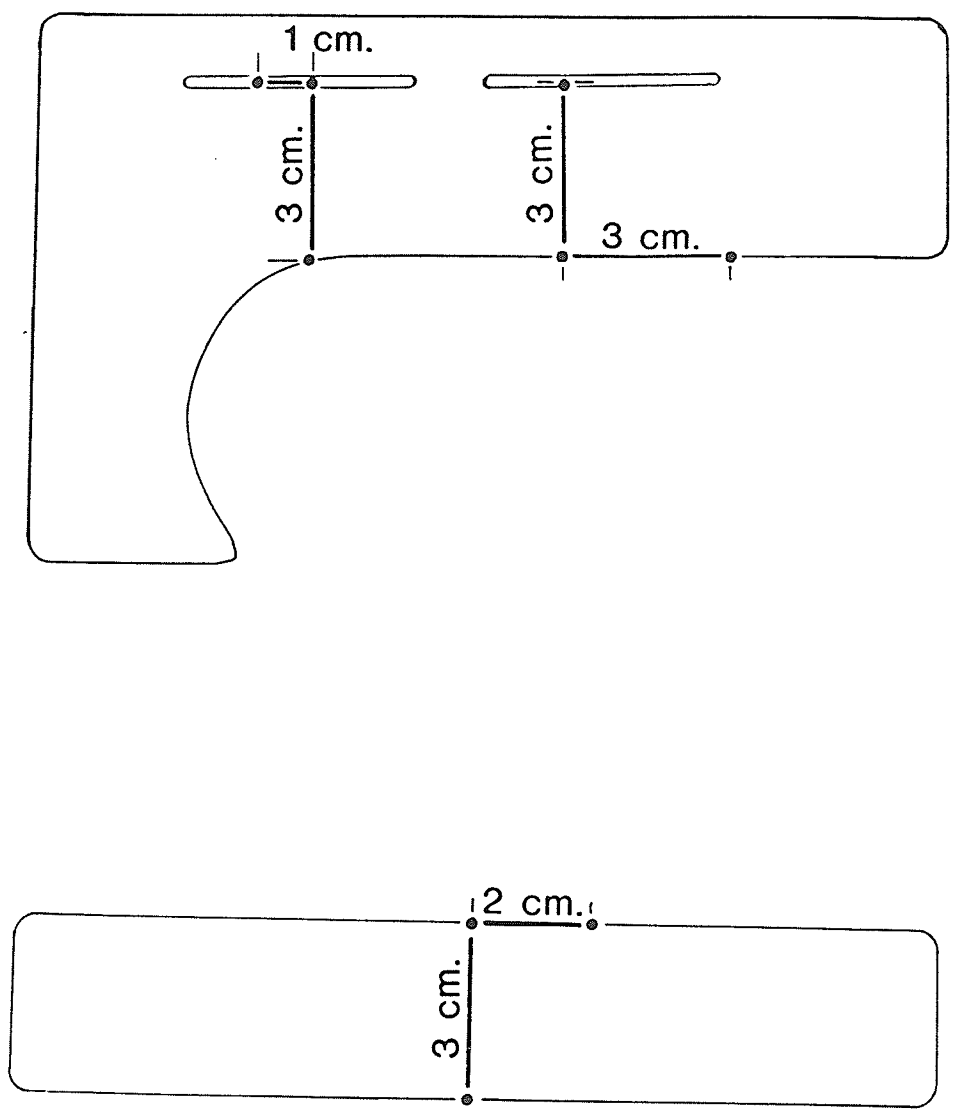

Figure 3

Figure 4: Electrode placement. Reference points and bipolar electrode placement for the anterior temporal, posterior temporal, and masseter muscles.

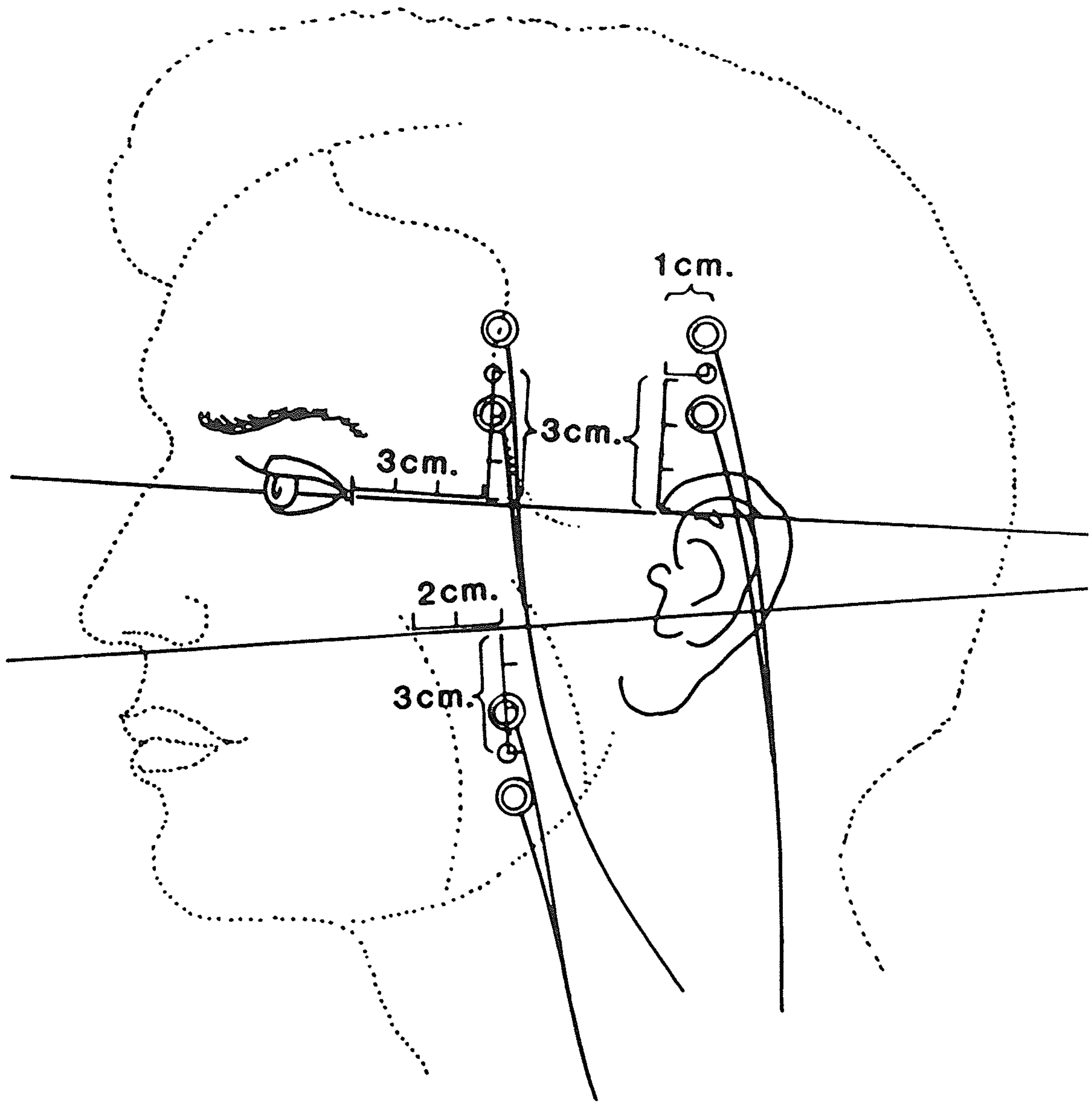

Figure 4

No. 650454). Electrode resistances were always less than 30 Kohm.

5. Experimental Protocol

The recordings were done in the orthodontic clinic of the Preventive Dental Science Department of the University of Manitoba. A d.c. signal generator of 1 millivolt was used for the calibration of the EMG apparatus prior to every recording. All recordings were made at a paper speed of 5 mm per second.

Patients were asked to:

a. clench fully in IP and RCP* with no acrylic registration between the teeth (no splint).

b. clench fully in RCP, IP, and MP with the appropriate acrylic registration between the teeth (splint).

c. clench on the splints (RCP, IP, and MP) at 10% of full clenching (partial clenching), determined with a voltmeter with an impedance of 20,000 ohm/volt, and connected to the output of the right superficial masseter muscle.

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* During clenching in the RCP without splint, the subjects were not allowed to come forward into the IP.

The partial clenching task was incorporated to observe the muscular behaviour under a different task than full clenching. It was speculated that the nature of the full clenching task could override some of the reflex inhibitions present in the system. This type of partial recording has been undertaken previously by Young and Winter, 1983.

Patients were trained to achieve full effort (100%) and partial effort (10%) in one second, and to maintain the biting force for three seconds.

Each biting maneuver was recorded three times. A minimum pause of two minutes was programmed between every task to avoid muscle fatigue, as suggested by Sheikholeslam (1985).

6. Quantitation of EMG Recordings

The linear envelope signal ("moving average") closely follows the amplitude of the peaks of the raw EMG (Winter, 1983). To obtain a mean value per position during full clenching, the three maximum EMG peaks of the three clenches per position were averaged (see Figure 5). For partial clenching (10%) three measurements were taken per bite in the middle part of the registration at one second intervals. Thus nine measurements were taken per position and averaged (see Figure 5). All data was converted to microvolts.

Figure 5: Quantitation of EMG. Derivation of mean values per position during full and partial clenching. Vertical lines represent the position and height of the selected measurements per bite. Data was converted to microvolts.

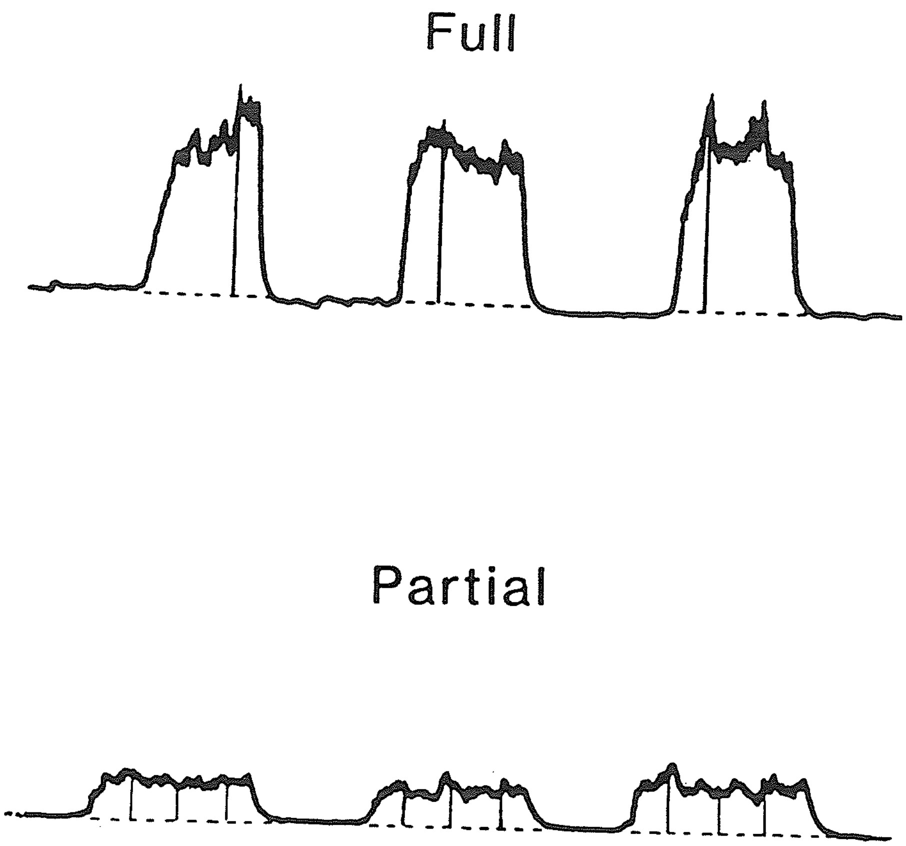

Figure 5

C. The Relationship Between Masticatory Muscles (biting to positioning ratios)

The preliminary hypothesis of the ideal jaw position regarding muscle activity considered the relationships between the biting and positioning functions. It was hypothesized that the ideal position was that one which allows the maximal biting activity (masseter muscle) and requires the lowest positioning activity (posterior temporal muscle). [Unsuccessful attempts were made to design a surface recording system for the lateral pterygoid muscles which are considered one of the major positioning muscles (DuBrul, 1980)].

In order to combine the biting and positioning components of the masticatory muscles, five ratios were designed (see page 37). The numerator element represents the biting muscle(s) and the denominator element represents the positioning muscle(s). The anterior temporal muscle was considered to have dual biting and positioning components, and as such was placed in the numerator or denominator in different ratios.

With this assumption, the ideal position would have the highest ratio since it would allow the maximal biting activity and/or require the lowest positioning activity.

D. Error Studies

Using the variability among the repeated measurements on the X or Y axis from each side, the standard deviation of the error of measurement was calculated by pooling these variables as follows:

$$sd = \sqrt{\frac{\sum_{j=1}^{m} \sum_{i=1}^{n} \left(X_{ij} - \bar{X}_j\right)^2}{m\,(n-1)}}$$

where m is the number of sites, and n, the number of repeated measurements per site (Chebib and Burdick, 1973). The maximum error was calculated by multiplying the standard deviation by the t value for the respective degrees of freedom [m(n-1)] at a 99% probability level, i.e., 99% of the measurements will have an error not exceeding the maximum error shown below.

1. Buhnergraph Method Error

The objective of this study was to ascertain the amount of variability in the X and Y axes measurements using the Buhnergraph method. Three subjects were used (m=6) and one registration in the IP was taken per subject. Then, the

Buhnergraph was utilized three times (n=3) on the IP registration to assess the Buhnergraph recording error (see appendix Table Ia).

The maximum error in the X axis was .122 mm and the maximum error in the Y axis was .152 mm. The casts were firmly seated in the records to avoid rotation of the Buhnergraph, as Lundeen (1974) suggested.

2. RCP Registration Error (using the calibrated spring)

The aim of this study was to evaluate the reliability of the RCP registrations. Three subjects were used (m=6) and the registration was taken three times per subject (n=3) at one sitting (see appendix Table IIa). The maximum error in the X axis was .152 mm and in the Y axis was .174 mm.

It has been shown that the RCP position can be recorded with good precision (Posselt, 1952). Ingervall et al (1971) tried varying the external pressure to record the RCP and recommended a strong dorsal pressure against the chin. The registration error of this study is comparable to those of Ingervall et al (1971) using intra-oral graphic recording. He found a maximum error of .25 mm on the X axis.

3. MP Registration Error

The goal of this study was to evaluate the reliability of the MP registration. Three subjects were used (m=6) and the registration was taken three times per subject (n=3) at one sitting (see appendix Table IIIa).

The maximum error in the X axis was .336 mm and the maximum error in the Y axis was .427 mm. These are close to those reported by Shafagh et al (1975) who found a maximum error of .43 mm in the X axis and of .66 mm in the Y axis.

4. Splint Distortion Error

As the registration records were made with autopolymerizing acrylic, the aim of this study was to evaluate the acrylic volume changes due to contraction following initial polymerization. Two IP registrations were made on one subject: one with acrylic, and the other with a very accurate (Fattore et al 1984) polyether recording medium (Ramitec Premier Dental Products, Norristown, PA). Measurements of the X and Y axes changes between the two registrations were obtained on six different consecutive days (m=2, n=6). The maximum error along the X axis was .126 mm and along the Y axis was .253 mm (see appendix Table IVa).

5. Within Subject Reliability of Electromyographical Peak and Average Amplitudes

This study was undertaken to determine the reliability of the electromyographical recordings within subjects using the variability among the three biting maneuvers per position (n=3). Ten subjects were used for the study (m=10) (see appendix Table Va).

The maximum error for full clenching was 72.04 microvolts and the maximum error for partial clenching (10%) was 15.13 microvolts. They both represent a 10% variability in the recordings. This error is within the range of similar studies on the biceps muscles (Young and Winter, 1983). They found a variability ranging from 8% to 10%.

6. Variability of Right and Left Muscular Activity with Anteroposterior Changes of the Mandible.

This study was performed to determine if pooling of the right and left muscle EMG data was feasible.

The right and left masseter muscle activity in IP was not significantly different from the right and left masseter muscle activity in MP at a probability level of .99% (see appendix Table VIa).

E. Statistical Analysis

Since there were two types of factors, between subjects (groups), and within subjects, a mixed analysis of variance was used (Becker and Chebib, 1969). In the analysis of variance, inter-subject variation in the trend is used to test the significance of the examined trend. Hence, a significant trend implies small inter-subject deviations. It was assumed in the study that the effect of each factor was multiplicative (nonadditive) that is to say, the effect of position (RCP, IP, and MP) on the muscle activity is a percentage difference rather than an absolute increment. Similarly, the difference in the muscle activity between groups is a percentage. In order to accomplish this end, a logarithmic transformation was used. Because of the occurrence of zero values in the data, the log (X + 1) transformation was best. This transformation has an extra advantage: it allows better distribution of the data and meets the assumptions underlying the analysis of variance (Steel and Torrie, 1960).

All comparisons were made with the logarithmic values of the data. The means and standard errors (Se) reported are those for the retransformed data in order to return to values for the real voltages. The standard errors apply to means multiplicatively, i.e., the variability for each mean is obtained by multiplying and dividing the mean by the Se.

The right and left muscles were pooled since there were no significant changes between sides per position (see error studies).

Eight variables were designed for the analysis of the results. Variable number one, the mean activity of pooled pair of individual muscles (V1, muscles), contains all the data gathered from the subjects. In order to simplify the data and facilitate interpretation, seven other variables were created. Five of these variables are the relationships between different muscles and are presented as the following ratios: variable number two, the ratio of the sum of the mean activity of masseter and anterior temporal muscle to posterior temporal muscle [V2, (M + AT)/PT], variable number three, the ratio of the mean activity of the masseter to anterior temporal muscle (V3, M/AT), variable number four, the ratio of the mean activity of the masseter to posterior temporal muscle (V4, M/PT), variable number five, the ratio of the mean activity of the anterior temporal to posterior temporal muscles (V5, AT/PT), and variable number six, the ratio of the mean activity of the masseter to the sum of anterior temporal and posterior temporal muscles [V6, M/ (AT + PT)]. Variable number seven, is the sum of the mean activity of the masseter, anterior temporal, and posterior temporal muscles (V7, sum). Variable number 8, is the ratio of the mean activity of each individual muscle without splint to that with splint [no splint to splint ratio (V8, NS/S)].

The ratios in V2, V3, V4, V5, V6 and V8 were calculated per subject and not derived from the collected means for all the subjects as in V1.

For each variable (except V8), two types of analysis (A and B) were performed, as not all of the conditions were present in the three registration positions.

Analysis A (splint only) involves V1 to V7. Analysis A for V1 contains comparisons by muscle (masseter, anterior temporal, and posterior temporal), position (RCP, IP, and MP), groups (control, class II division 2, and dual bite), and activity [full (100%) and partial (10%)]. Anaysis A for V2 to V7 contains comparisons by position (RCP, IP, and MP), groups (control, class II division 2, and dual bite), and activty (full and partial).

Analysis B (full only) involves V1 to V8. Analysis B for V1 contains comparisons by muscle (masseter, anterior temporal, and posterior temporal), position (two positions only, RCP and IP), groups (control, class II division 2, and dual bite), and splint (with splint and without splint). Analysis B for V2 to V7 contains comparisons by positions (RCP and IP), groups (control, class II divisoin 2, and dual bite), and splint (with and without splint). Analysis B for V8 contains comparisons by muscles (masseter, anterior temporal, and posterior temporal), position (RCP and IP), and groups (control, class II division 2, and dual bite).

The F ratio was used to determine the significance of each comparison, per variable, per analysis, using the 95% and 99% level of significance ($p < .05$ and $p < .01$). Individual means of special interest contained in significant comparisons were compared utilizing the standard errors of those means at 99% level of significance.

RESULTS

A. RCP, IP, and MP Relationships

The distance between the three jaw registration positions (RCP, IP, and MP) was recorded using the Buhnergraph method. The subjects were grouped according to the RCP-IP distance. Measurements along the X and Y axes of the RCP-IP distance were obtained per subject. A simple analysis of variance was performed to see if there was a significant difference between groups in the X and Y axes measurements of the RCP-IP distance (see Table III).

There was no significant difference in any of the measurements between the control and the class II division 2 groups. The Y axis measurement showed no significant difference between the control and the dual bite group. The X axis measurement enables one to discriminate better between the groups. It showed a significant difference between control and dual bite groups, and between class II division 2 and dual bite groups.

Measurements along the X axis were selected to represent the RCP-IP, RCP-MP, and IP-MP distance. For the dual bite group, the most forward IP position was used to record the distance. The mean and standard deviations of the RCP-IP, RCP-MP, and IP-MP distance along the X axis per group are shown in Table IV.

TABLE III

Mean ($\bar{X}$), standard deviation (Sd), and standard error (Se) of the RCP-IP distance along the X and Y axes per group and their test of significance.

	X axis			Y axis		
Groups	$\bar{X}$	Sd	Se	$\bar{X}$	Sd	Se
Control (GRP1)	0.65	0.19	0.056	0.75	0.47	0.13
Class II division (GPR 2)	0.36	0.20	0.054	0.44	0.36	0.10
Dual bite (GRP3)	3.86	1.74	0.52	1.15	0.65	0.20
Significance $p < .01$.	GRP3 > GRP1, GRP2			GRP3 > GRP2		

TABLE IV

Mean ($\bar{X}$) and standard deviation (Sd) of the RCP-IP, RCP-MP, and IP-MP distance along the X axis per group.

	RCP-IP		RCP-MP		IP-MP	
Groups	$\bar{X}$	Sd	$\bar{X}$	Sd	$\bar{X}$	Sd
Control	0.65	0.19	0.81	0.45	0.33	0.30
Class II division 2	0.36	0.20	0.73	0.46	0.46	0.36
Dual bite	3.86	1.74	1.49	1.09	2.46	1.50

B. Results of the Mixed Analysis of Variance

A mixed analysis of variance was used to assess the main effects and interaction of the data. The F ratio was used to determine the significance of each comparison per variable per analysis, using the 95% and 99% level of significance ($p < .05$ and $p < .01$). Individual means of special interest contained in significant comparisons were compared utilizing the standard errors of those means at a 99% level of significance.

The results are displayed in two ways: figures of EMG data and tables. The tables more relevant for the study are presented in the body of the thesis. Tables of variables not used in the discussion are presented in the appendix.

The two major components of the results are related first, to the muscle activity with changes in the anteroposterior position of the mandible with splints (RCP, IP, and MP), and second, to the muscle activity during full clenching in the RCP and IP with and without splint. The first component of the results is included in analysis A (splint only) and the second in analysis B (full clenching only).

To give an idea of the inter-subject variation in the trend, the raw EMG data during full clenching with and without splint in the RCP is displayed in the appendix (see Table VIIa).

The significance of each comparison per variable for analysis A is presented in Tables V and IX and for analysis B in Tables XIV and XV. The comparisons considered most relevant to the study are indicated by square brackets in each table.

1. Results of Analysis A (Splint Only) for Variable 1

Analysis A (splint only) was designed to examine the effect of jaw position (RCP, IP, and MP) on muscle activity during full and partial clenching in all three groups of subjects.

In general, the results of analysis A show that in the RCP there was a hypoactivity of the masseter muscle and hyperactivity of the anterior temporal and posterior temporal muscles. It also shows that there was not a significant change in the muscle activity between the IP and MP positions.

Table V contains the significance of main effects and interactions of analyisis A for variable 1.

An overview of Table V shows that almost all of the comparisons were significant. The complicated interactions between the analysed comparisons suggest significant differences between groups, muscles, positions, and activities.

To explore the specific location of the significant difference within comparisons, the following comparisons were

TABLE V

Significance of main effects and interactions of analysis A (splint only) for variable 1 (individual muscles) related to groups, jaw position, and level of clenching (comparisons by group, muscle, position, and activity).

Source of variance	Level of significance
Group	X X
Muscle	X X
Group by muscle	NS
Position	X X
Group by position	X
Muscle by position	[X X]
Group by muscle by position	X X
Activity	X X
Group by activity	NS
Muscle by activity	X X
Group by muscle by activity	X X
Position by activity	X X
Group by position by activity	X
Muscle by position by activity	[X X]
Group by muscle by position by activity	[X]

NS = not significant

X = $p < .05$

X X = $p < .01$

[ ] = most relevant comparisons.

selected from V1: comparisons by group, muscle, position, and activity; by muscle, position, and activity; and by muscle and position.

i. Comparison by group, muscle, position, and activity

a. Control Group

The mean masseter muscle activity during full and partial clenching was not significantly different between positions RCP, IP, and MP (see Table VI and Figures 6 and 7).

The mean anterior temporal muscle activity during full clenching was not significantly different between positions RCP, IP, and MP. During partial clenching, the mean anterior temporal muscle activity was significantly higher in the RCP than in the IP and MP positions. There was no significant difference in the mean anterior temporal muscle activity during partial clenching between the IP and MP positions (see Table VI and Figures 6 and 7).

The mean posterior temporal muscle activity during full clenching was not significantly different between positions RCP, IP, and MP. During partial clenching the mean posterior temporal muscle activity was significantly higher in the RCP

TABLE VI

Comparison of mean activity in microvolts by group, muscle, position and activity. (splint only). (+)

	Masseter						Anterior Temporal						Posterior Temporal						
	RCP		IP		MP		RCP		IP		MP		RCP		IP		MP		
	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	Se(+)
Control	581	62	652	54	668	57	890	191	904	83	943	90	733	53	655	21	690	20	1.069
Class II division 2	878	69	958	66	980	62	969	188	996	169	938	115	800	83	811	69	689	49	1.064
Dual bite	246	43	540	57	532	41	641	220	632	91	768	92	489	122	303	16	417	23	1.073

F = Full
P = Partial
(+) Retransformed data. Standard errors are applied to means multiplicatively.

Figure 6: Muscle activity during full clenching with splint in the RCP, IP, and MP positions, in a control subject. (Diagram on the upper left hand side indicates a control subject with splint). Reference lines on the right hand side indicate: vertical, 250 microvolts, and horizontal, one second.

RM: right masseter, LM: left masseter, RPT: right posterior temporal, LPT: left posterior temporal, RAT: right anterior temporal, LAT: left anterior temporal.

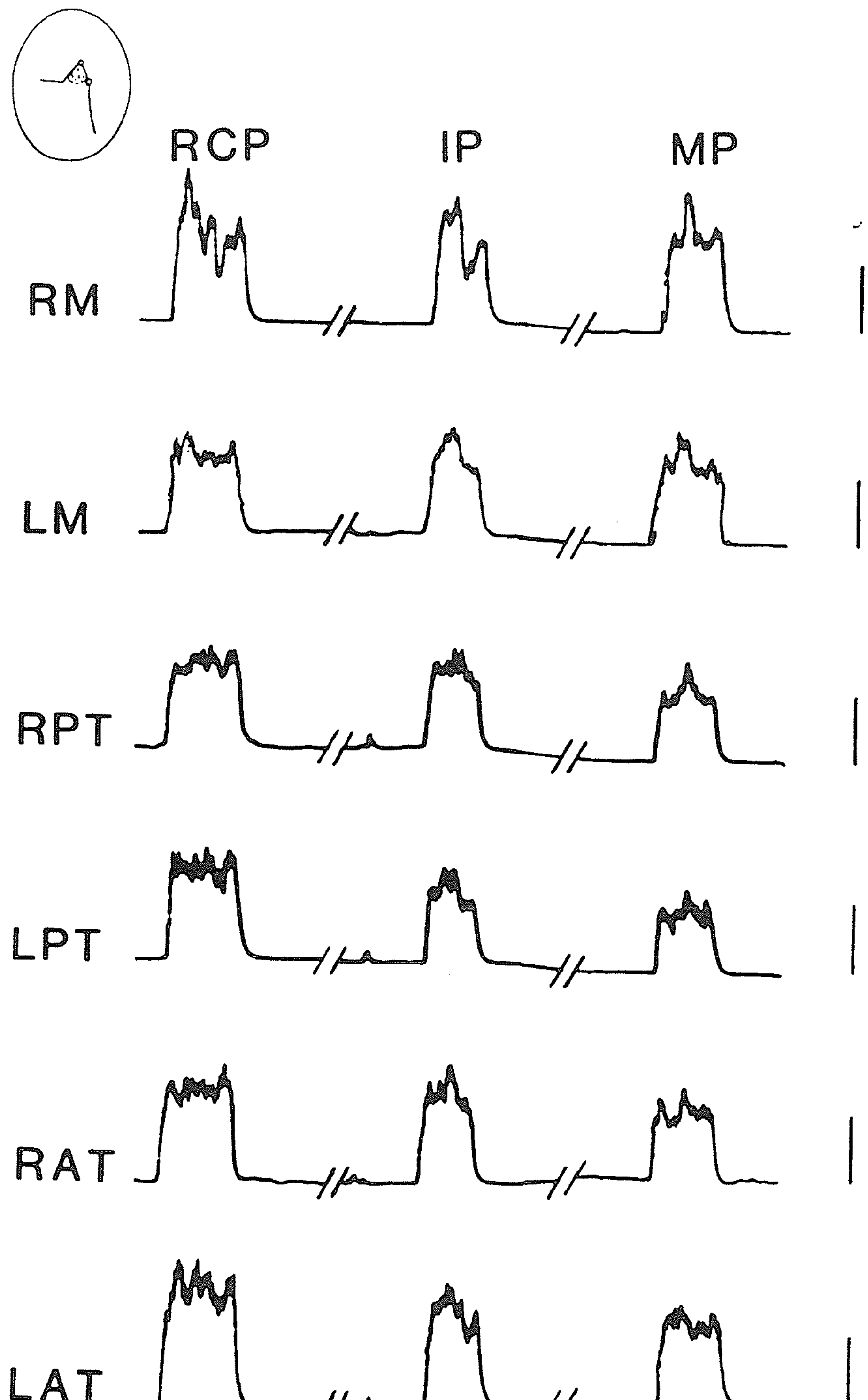

Figure 6

Figure 7: Muscle activity during partial clenching with splint in the RCP, IP, and MP positions, in a control subject. (Diagram on the upper left hand side indicates a control subject with splint). Reference lines on the right hand side indicate: vertical, 62 microvolts, and horizontal, one second.

RM: right masseter, LM: left masseter, RPT: right posterior temporal, LPT: left posterior temporal, RAT: right anterior temporal, LAT: left anterior temporal.

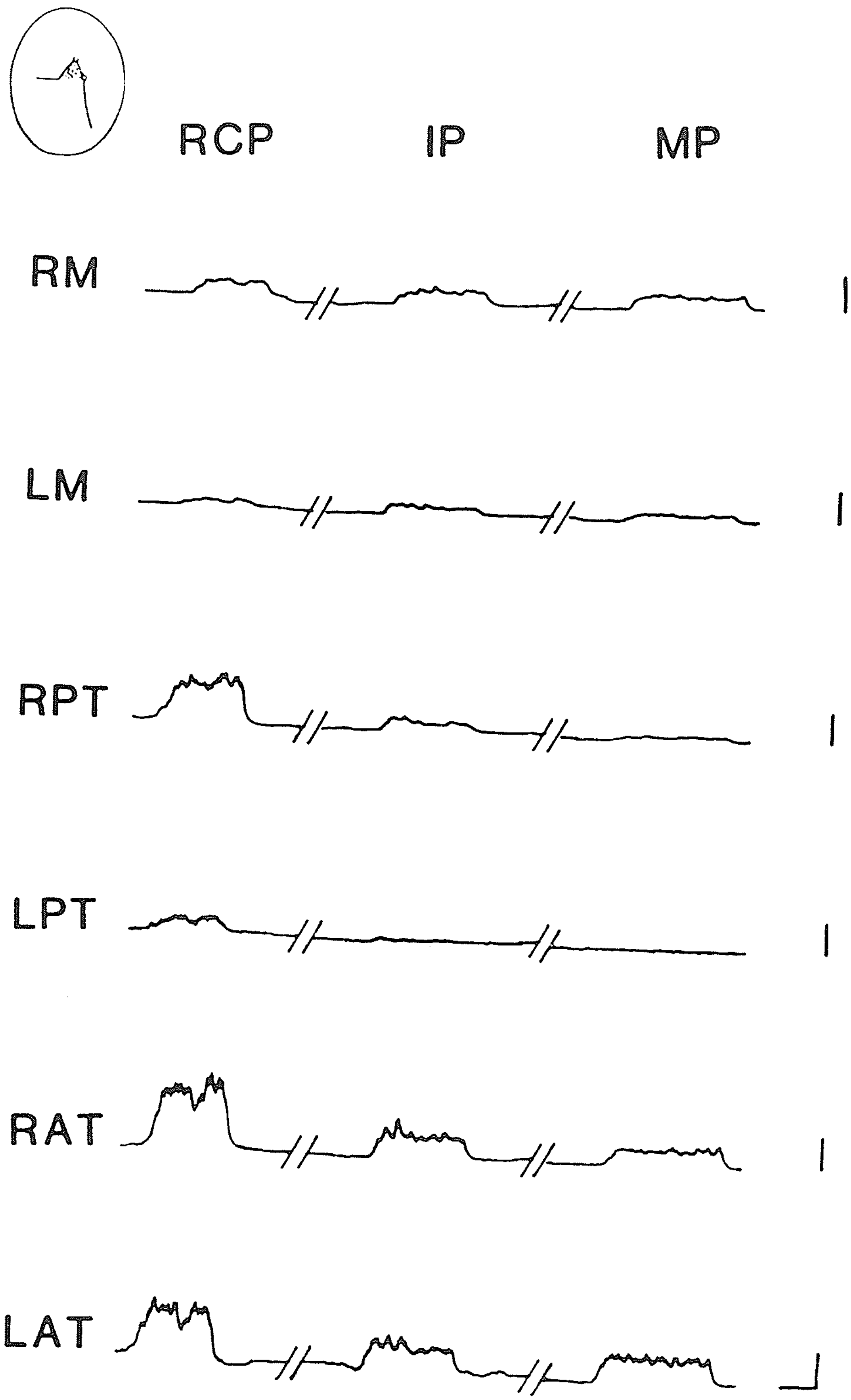

Figure 7

than in the IP and MP positions. There was no significant difference in the mean posterior temporal muscle activity during partial clenching between the IP and MP positions (see Table VI and Figures 6 and 7).

b. Class II Division 2 Group

The mean masseter muscle activity during full and partial clenching was not significantly different between positions RCP, IP, and MP (see Table VI).

The mean anterior temporal muscle activity during full clenching was not significantly different between positions RCP, IP, and MP. During partial clenching, the mean anterior temporal muscle activity was significantly lower in the MP than in the RCP and IP positions. There was no significant difference in the mean anterior temporal muscle activity between the RCP and IP positions (see Table VI and Figure 8).

The mean posterior temporal muscle activity during full clenching was not significantly different between positions RCP, IP, and MP. During partial clenching, the mean posterior temporal muscle activity was significantly lower in the MP than in the RCP and IP positions. There was no significant difference in the mean posterior temporal muscle activity between the RCP and IP (see Table VI and Figure 8).

Figure 8: Muscle activity during partial clenching with splint in the RCP, IP, and MP positions, in a class II division 2 subject. (Diagram on the upper left hand side indicates a class II division 2 subject with splint). Reference lines on the right hand side indicate: vertical, 125 microvolts, and horizontal, one second.

RM: right masseter, LM: left masseter, RPT: right posterior temporal, LPT: left posterior temporal, RAT: right anterior temporal, LAT: left anterior temporal.

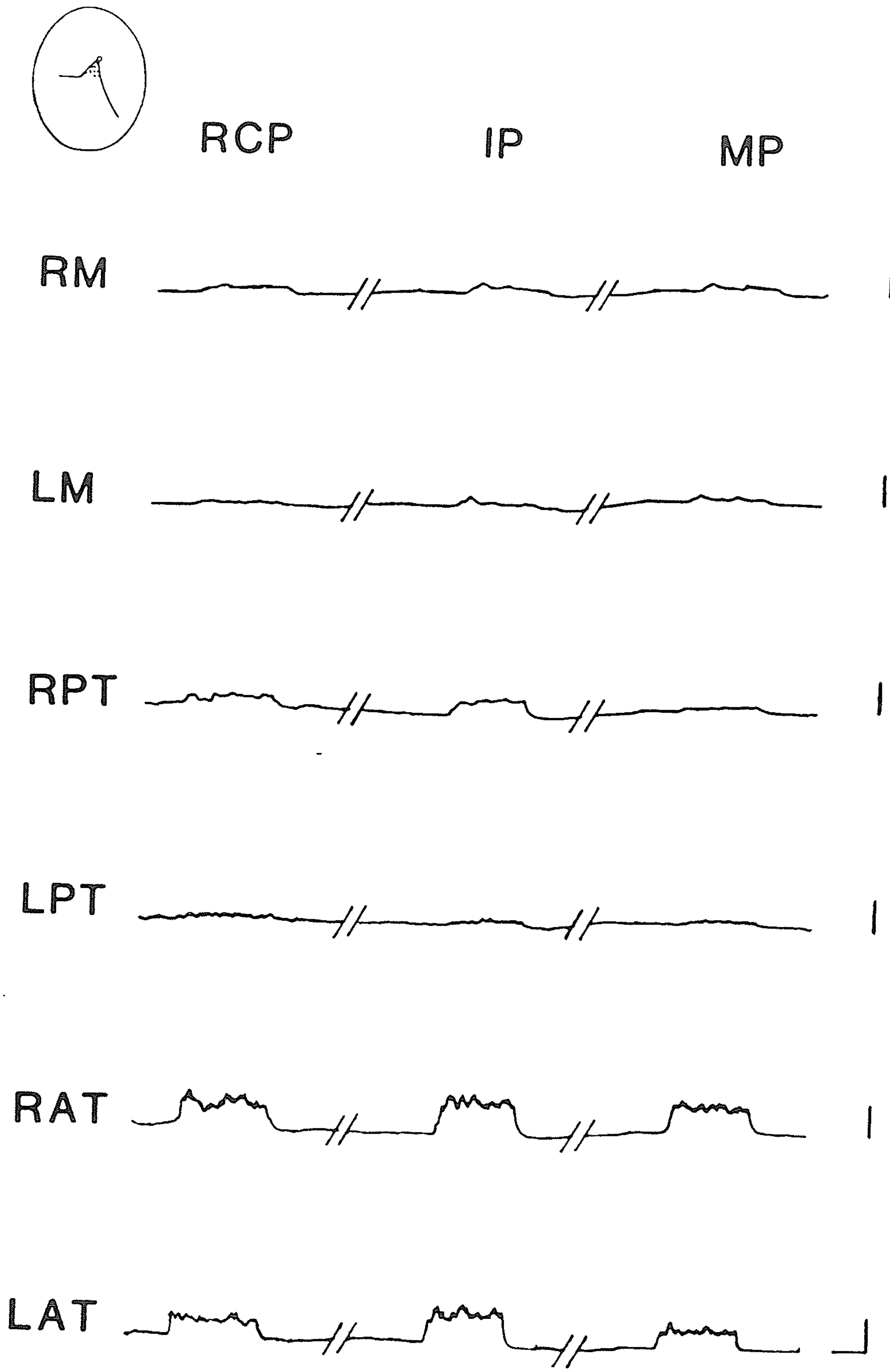

Figure 8

c. Dual Bite Group

The mean masseter muscle activity during full clenching was significantly lower in the RCP than in the IP and MP. There was no significant difference in the mean masseter muscle activity during full clenching between the IP and MP (see Figure 9). During partial clenching the mean masseter activity was significantly higher in the IP than in the RCP and MP positions. There was no significant difference during partial clenching in the mean masseter muscle activity between the RCP and MP positions (see Table VI).

The mean anterior temporal muscle activity during full clenching was not significantly different between positions RCP, IP, and MP. During partial clenching, the mean anterior temporal muscle activity was significantly higher in the RCP than in the IP and MP positions. There was no significant difference in the mean anterior temporal muscle activity between the IP and MP positions (see Table VI and Figure 9).

The mean posterior temporal muscle activity during full clenching was significantly lower in the IP than in the RCP and MP positions. There was no significant difference in the mean posterior temporal muscle activity between the RCP and MP positions. During partial clenching, the mean posterior temporal muscle activity was significantly higher in the RCP than in the IP and MP positions. There was no significant difference in the mean posterior temporal muscle activity during partial clenching

Figure 9: Muscle activity during full clenching with splint in the RCP, IP, and MP, in a dual bite subject. (Diagram on the upper left hand side indicates a dual bite subject with splint). Reference lines on the right hand side indicate: vertical, 250 microvolts, and horizontal, one second.

RM: right masseter, LM: left masseter, RPT: right posterior temporal, LPT: left posterior temporal, RAT: right anterior temporal, LAT: left anterior temporal.

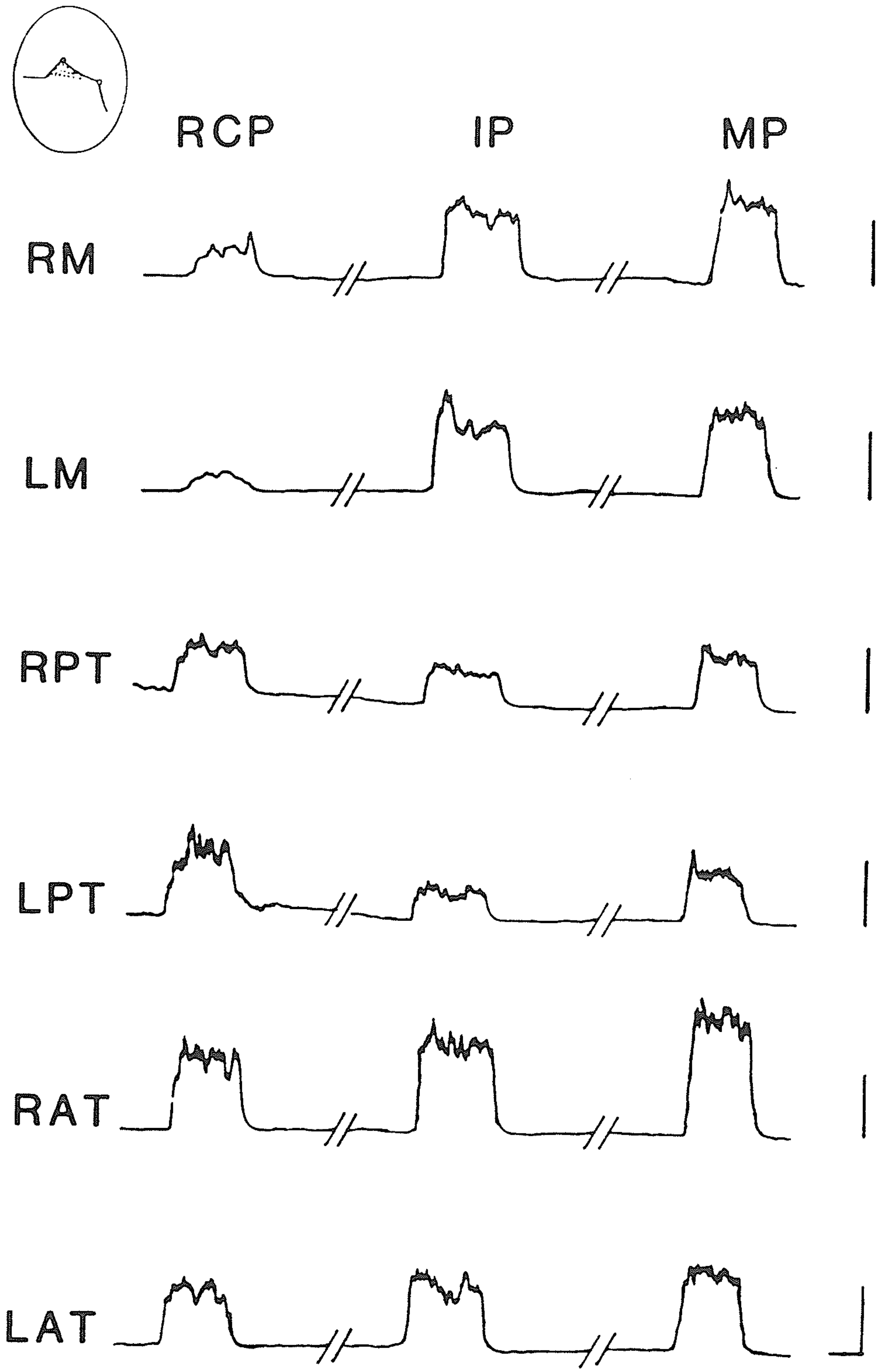

Figure 9

between the IP and MP positions (see Table VI and Figure 9).

d. Between Groups

The mean masseter activity during full clenching in the IP was significantly higher in the class II division 2 group than in the control and dual bite groups (see Table VI).

In the control group, during partial clenching, there was a significant change in the mean anterior temporal and posterior temporal muscle activity from RCP to IP while in the class II division 2 there was not (see Table VI).

The mean masseter activity during full clenching in the RCP was significantly lower in the dual bite group than in the control and class II division 2 groups (see Table VI).

The mean posterior temporal muscle activity during partial clenching in the RCP was significantly higher in the dual bite group than in the control and class II division 2 groups (see Table VI).

ii. Comparison by muscle, position, and activity (means are for all three groups)

The mean masseter muscle activity during full clenching was significantly lower in the RCP than in the IP and MP positions. There was no significant difference in the mean masseter muscle activity during full clenching between the IP and MP. During partial clenching the mean masseter muscle activity was not significantly different between positions RCP, IP, and MP (see Table VII).

The mean anterior temporal muscle activity during full clenching was not significantly different between positions RCP, IP, and MP. During partial clenching, the mean anterior temporal muscle activity was significantly higher in the RCP than in the IP and MP positions. There was no significant difference in the mean anterior temporal muscle activity between IP and MP positions (See Table VII).

The mean posterior temporal muscle activity during full clenching was significantly higher in the RCP than in the IP. There was no significant difference in the mean posterior temporal muscle activity during full clenching between the MP and RCP and between the MP and IP positions. During partial clenching the mean posterior temporal muscle activity was significantly higher in the RCP than in the IP and MP positions. There was no significant difference in the mean posterior temporal muscle activity during partial clenching between the IP and MP positions (see Table VII).

TABLE VII

Comparison of mean activity in microvolts by muscle, position, and activity (means are for all three groups),(splint only). (+)

Muscles	RCP		IP		MP		
	Full	Partial	Full	Partial	Full	Partial	Se(+)
Masseter	501	57	695	59	703	52	1.039
Anterior temporal	821	199	828	108	878	99	1.039
Posterior temporal	659	81	544	29	583	28	1.039

(+) Retransformed data. Standard errors are applied to means multiplicatively.

iii. Comparison by muscle and position (means are for all three groups and both activity levels).

The mean activity of the masseter muscle was significantly lower in the RCP than in the IP position. The mean masseter activity was lower in the RCP than in the MP, but this was not significant. There was no significant difference in the mean masseter activity between the IP and MP positions (see Table VIII).

The mean activity of the anterior temporal muscle was significantly higher in the RCP than in the IP and MP positions. There was no significant difference in the mean anterior temporal muscle activity between the IP and MP (see tabel VIII).

The mean activity of the posterior temporal muscle was significantly higher in the RCP than in the IP and MP positions. There was no significant difference in the mean posterior temporal muscle activity between the IP and MP positions (see Table VIII).

2. Results of Analysis A (Splint Only) for Variables 2-7

Table IX contains the significance of the main effects and interactions of variables 2, 3, 4, 5, 6, and 7. A survey of Table IX demonstrates that comparisons by position and by group and position were significant for all of the variables.

TABLE VIII

Comparison of mean activity in microvolts by muscle and position (means are for all three groups and both activity levels, splint only). (+)

Muscles	RCP	IP	MP	Se(+)
Masseter	170	204	193	1.037
Anterior temporal	405	300	296	1.037
Posterior temporal	232	127	131	1.037

(+) Retransformed data. Standard errors are applied to means multiplicatively.

TABLE IX

Significance of main effects and interactions of analysis A (splint only) for variables 2 [(M + AT)/PT ratio], 3 (M/AT ratio), 4 (M/PT ratio), 5 (AT/PT ratio) 6 [M/(AT + PT) ratio], and 7 (sum M + AT + PT) related to groups, jaw position, and level of clenching (comparisons by group, position, and activity).

Source of variance	Level of significance per variable					
	V_2	V_3	V_4	V_5	V_6	V_7
Group	NS	NS	NS	NS	NS	XX
Position	XX	XX	[XX]	XX	XX	XX
Group by position	XX	XX	[XX]	XX	XX	X
Activity	XX	XX	XX	XX	NS	XX
Group by activity	X	X	XX	NS	X	NS
Position by activity	XX	XX	[XX]	NS	NS	XX
Group by position by activity	NS	NS	[X]	NS	NS	XX

NS = not significant

X = p < .05

XX = p < .01

[ ] = most relevant comparisons.

This is interpreted to mean that the position has a significant effect on the activity, and that the effect of the position differs from group to group.

Variable 4 (M/PT ratio) enabled a better determination of the source of variance and was selected to compare individual means of special interest of each significant comparison. The following comparisons were selected from variable 4: comparisons by position, by group and position, by position and activity, and by group, position and activity.

i. Comparison by position (means are for all three groups and both activity levels)

The ratio of the mean masseter activity to the mean posterior temporal activity (M/PT) was significantly lower in the RCP than in the IP and MP positions. There was no significant difference in the M/PT ratio between the IP and MP positions (see Table X).

ii. Comparison by group and position (means are for both activity levels)

In the control group the M/PT ratio in the RCP was

TABLE X

Comparison of variable 4 (ratio of the mean masseter muscle activity to the mean posterior temporal muscle activity, M/PT) by position. Means are for all three groups and both activity levels, splint only). (+)

Positions	M/PT ratio	Se(+)
RCP	0.879	1.035
IP	1.631	1.035
MP	1.679	1.035

(+) Retransformed data. Standard errors are applied to means multiplicatively.

significantly lower than in the IP and MP. There was no significant difference in the M/PT ratio between the IP and MP (see Table XI).

In the class II division 2 group the M/PT ratio was not significantly different between the RCP, IP, and MP positions (see Table XI).

In the dual bite group the M/PT ratio was significantly lower in the RCP than in the MP, which in turn was significantly lower than in the IP position (see Table XI).

In the control group there was a significant increase in the M/PT ratio in going from the RCP to the IP position, while in the class II division 2 group this was not so (see Table XI).

The dual bite group has a significantly lower M/PT ratio in the RCP position and a significantly higher M/PT ratio in the IP position than the control and the class II division 2 groups (see Table XI).

iii. Comparison by position and activity (means are for all three groups)

During full and partial clenching, the M/PT ratio was

TABLE XI

Comparison of variable 4 (ratio of the mean masseter muscle activity to posterior temporal muscle activity, M/PT) by group and position (means are for both activity levels, splint only). (+)

Groups	M/PT ratio			
	RCP	IP	MP	Se(+)
Control	1.089	1.741	1.805	1.064
Class II division 2	1.070	1.167	1.511	1.059
Dual bite	0.534	2.828	1.728	1.066

(+) Retransformed data. Standard errors are applied to means multiplicatively.

significantly lower in the RCP than in the IP and MP. There was no significant difference in the M/PT ratio between the IP and MP positions during full and partial clenching (see Table XII).

During full clenching, the decreased M/PT ratio in the RCP was due to a combined decrease in activity of the masseter muscle and increased activity of the posterior temporal muscle. During partial clenching, the decreased M/PT ratio in the RCP was related to an increase in the posterior temporal muscle activity (see Table VII).

iv. Comparison by group, position, and activity

In the control group the M/PT ratio during full clenching was not significantly different between the RCP, IP, and MP positions. During partial clenching, the M/PT ratio was significantly lower in the RCP than in the IP and MP. There was no significant difference in the M/PT ratio during partial clenching between the IP and MP positions (see Table XIII).

In the class II division 2 group there was no significant difference in the M/PT ratio during full and partial clenching between the RCP, IP, and MP positions (see Table XIII).

TABLE XII

Comparison of variable 4(ratio of the mean masseter muscle activity to the mean posterior temporal muscle activity, M/PT) by position and activity (means are for all three groups, splint only). (+)

Positions	M/PT ratio Full	M/PT ratio Partial	Se(+)
RCP	0.849	0.909	1.037
IP	1.365	2.396	1.037
MP	1.280	2.147	1.037

(+) Retransformed data. Standard errors are applied to means multiplicatively.

TABLE XIII

Comparison of variable 4 (ratio of the mean masseter muscle activity to the mean posterior temporal muscle activity, M/PT) by group, position, and activity, splint only). (+)

	M/PT ratio						
	RCP		IP		MP		
	Full	Partial	Full	Partial	Full	Partial	Se(+)
Control	0.823	1.398	1.046	2.672	0.990	2.953	1.066
Class II division 2	1.152	0.995	1.228	1.113	1.466	1.558	1.061
Dual bite	0.614	0.455	1.910	4.035	1.409	2.083	1.071

(+) Retransformed data. Standard errors are applied to means multiplicatively.

In the dual bite group the M/PT ratio during full clenching was significantly lower in the RCP than in the IP and MP positions. There was no significant difference in the M/PT ratio during full clenching in the IP and MP positions. During partial clenching the M/PT ratio was significantly lower in the RCP than in the MP, which in turn was significantly lower than in the IP position (see Table XIII).

3. Results of analysis B (full only) for variables 1-8

Analysis B was designed to look at the effect of the splint (with splint and without splint) on muscle activity during full clenching in the RCP and IP in all three groups of subjects.

In general, the results of analysis B show that in the RCP without splint there was a significant overall decrease in muscle activity when compared to that with splint. This effect was absent in the IP. The raw EMG data during full clenching with and without splint in the RCP is displayed in the appendix (see Table VIIa).

Table XIV contains the significance of the main effects and interactions of variable 1 (individual muscles) and variable 8 (ratio of the mean activity of each individual

TABLE XIV

Significance of main effects and interactions of analysis B (full only) for variables 1 (individual muscles) and 8 (ratio of the mean activity of each individual muscle without splint to that with splint) related to groups, jaw position, and splint (comparisons by group, muscle, position, and splint).

Source of variance	Level of significance per variable	
	V_1	V_8
Group	XX	NS
Muscle	XX	XX
Group by muscle	X	XX
Position	XX	XX
Group by position	NS	NS
Muscle by position	XX	[XX]
Group by muscle by position	NS	NS
Splint	XX	
Group by splint	NS	
Muscle by splint	XX	
Group by muscle by splint	NS	
Position by splint	XX	
Group by position by splint	NS	
Muscle by position by splint	[XX]	
Group by muscle by position by splint	NS	

NS = not significant
X = $p < .05$
XX = $p < .01$
[ ] = most relevant comparisons

muscle without splint to that with splint). Table XV contains the significance of the main effects and interactions of variable 2 [(M + AT)/PT ratio], variable 3 (M/AT ratio), variable 4 (M/PT ratio), variable 5 (AT/PT ratio), variable 6 [M/(AT + PT) ratio], and variable 7 (sum of M + AT + PT).

A perusal of Table XIV reveals that variable 1 is significant in the comparison by groups. When the comparisons in variable 1 involve other factors, e.g. comparison by group and position; by group, muscle, and position; by group and splint; by group, muscle, and splint; by group, position, and splint; and by group, muscle, position, and splint; the comparisons were not significant. This is interpreted to mean that the groups are different but affected similarly by other factors.

In Table XIV the comparisons by muscle, by muscle and position, by muscle and splint, and by muscle, position and splint, were significant. This is interpreted to mean that the muscles are different and that the splint and position had an affect on the muscle activity.

An analysis of Tables XIV and XV shows that comparisons by position and by splint were significant for all variables. This is interpreted to mean that the splint had a significant affect on the activity but that not all the positions were similarly affected.

To determine the significant differences within each

TABLE XV

Significance of main effects and interactions of analysis B (full only) for variables 2[(M + AT)/PT ratio], 3 (M/AT ratio), 4 (M/PT ratio), 5 (AT/PT ratio), 6[M/(AT +PT) ratio], and 7 (sum M + AT + PT) related to groups, jaw position, and splint (comparisons by group, position, and splint).

	Level of significance per variable					
Source of variance	V_2	V_3	V_4	V_5	V_6	V_7
Group	NS	XX	NS	NS	XX	XX
Position	XX	XX	XX	XX	XX	XX
Group by position	XX	X	XX	X	X	NS
Splint	XX	XX	XX	XX	XX	XX
Group by splint	NS	NS	NS	NS	NS	NS
Position by splint	XX	XX	XX	NS	XX	XX
Group by position by splint	NS	X	XX	NS	XX	NS

NS = not significant

X = $p \leq .05$

XX = $p < .01$

comparison from Tables XIV and XV, the following variables and comparisons were selected: from variable 1, the comparison by muscle, position, and splint; and from variable 8, the comparison by muscle and position.

i. Variable 1, comparison by muscle, position, and splint (means are for all three groups)

The mean masseter anterior temporal and posterior temporal muscle activity was significantly lower during clenching in the RCP without rather than with a splint. The masseter muscle was the most affected muscle without the splint while clenching in the RCP (see Table XVI and Figure 10).

The mean masseter, anterior temporal, and posterior temporal muscle activity was not significantly different during clenching in the IP with and without a splint (see Table XVI).

ii. Variable 8, comparison by muscle and position (means are for all three groups)

The ratio of the mean activity of each individual

TABLE XVI

Comparison of mean activity in microvolts by muscle, position, and splint (means are for all three groups, full clenching only). (+)

	RCP		IP		
Muscles	Splint	No splint	Splint	No splint	Se(+)
Masseter	501	12	695	544	1.088
Anterior temporal	821	249	828	786	1.088
Posterior temporal	659	344	544	605	1.088

(+) Retransformed data. Standard errors are applied to means multiplicatively.

Figure 10: Muscle activity during full clenching in the RCP with and without splint in a control subject. (Superior diagrams indicate: on the left, a control subject with splint; on the right, without splint. Reference lines on the right hand side represent: vertical, 250 microvolts; horizontal, one second.
RM: right masseter, LM: left masseter, RPT: right posterior temporal, LPT: left posterior temporal, RAT: right anterior temporal, LAT: left anterior temporal.

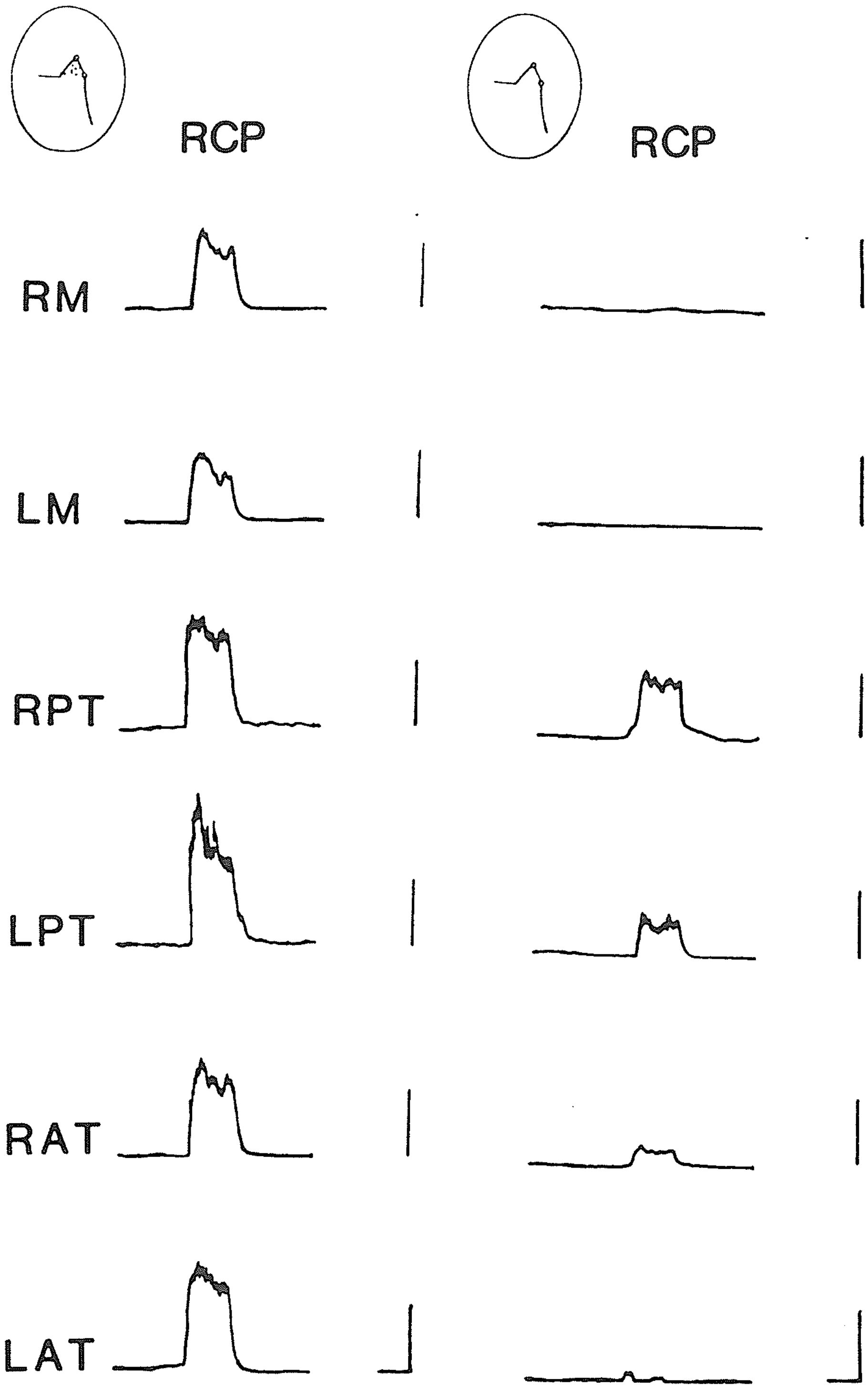

Figure 10

muscle without a splint to that with a splint was significantly lower in the RCP than in the IP (see Table XVII).

TABLE XVII

Comparison of variable 8 (ratio of the mean activity of each individual muscle without splint to that with splint, NS/S ratio) by muscle and position (means are for all three groups, full clenching only). (+)

	NS/S ratio		
Muscles	RCP	IP	SE (+)
Masseter	0.081	0.819	1.005
Anterior temporal	0.355	0.958	1.025
Posterior temporal	0.552	1.192	1.025

(+) Retransformed data. Standard errors are applied to means multiplicatively.

DISCUSSION

The objective of this study was to assess the electrical activity of masticatory muscles during full and partial clenching in three mandibular bite registration positions. Records were made with and without standardization of the distribution of occlusal contact. Three groups of subjects with different ranges of anteroposterior positioning of the mandible in occlusion were studied. Data was analyzed using a mixed analysis of variance.

The discussion of the results will be divided into five categories as follows:

A. Muscle compensation for unstable biting contacts

B. The retruded contact position (RCP) as an ideal position for maximal intercuspation

C. Muscular activity as a function of anteroposterior changes of the mandibular position (IP and MP)

D. Muscular activity in Angle's class II division 2 malocclusion

E. Muscular activity in dual bite malocclusion

A. Muscle Compensation for Unstable Biting Contacts

Clenching in the RCP without splint inhibited masseter muscle activity and reduced anterior temporal and posterior temporal muscular activity (see Table XVI and Figure 10).

The abolition of masseter muscle activity may be in part due to the unstable biting contact that is normally present in the RCP, since clenching in the same position with an acrylic bite splint which created stability in the dentition restored full masseter muscle activity (see Table XVI). In the dual bite group the position of the mandible may also contribute to the reduction of the masseter muscle activity in the RCP (see Table VI).

From the results of this experiment it could be inferred that the main occlusal determinant of maximal masseter isometric muscle contraction is the uniform distribution of tooth contact. Biomechanically, this can be expressed as the amount of stability in the dentition. To satisfy static equilibrium (stability) under any occlusal contact condition, the teeth, muscles, ligaments, and joints should combine roles so that the resultant force and moments on the mandible are zero. If the dentition takes the major role of stabilizing the mandible, i.e., there is good intercuspation, the masseter muscle can exert maximal isometric contractions. However, if stability is not provided in the dentition, i.e., there is a premature contact, the jaw muscles should stabilize the mandible as well as provide the biting force. Under such conditions the potential masseter muscle biting activity is severely reduced possibly to avoid damage to the structures involved in the compensatory stabilization.

The unstable biting condition present in the RCP can be visualized in a three dimensional relationship in which the steepness of the cuspal inclines in contact, and their orientation, could determine the X, Y and Z axes features of unstability.

Smith (1984) in a mathematical model of TMJ loading, demonstrated that posteriorly located premature contacts and premature contacts with lateral components resulted in distracting condyle forces and heavy loads in the articular tissues. He found that the masticatory musculature was incapable of dealing with this condition.

The muscle least affected during clenching in the presence of the unstable biting contact was the posterior temporal muscle (see Table XVII and Figure 10). The posterior temporal muscle has a short moment arm length and a high proportion of type I fibers (Smith, 1984; Eriksson, 1982). These features are in accordance with the mandibular stabilizing role attributed to the posterior temporal muscle by DuBrul (1980). The potential biting forces generated by recruitment of the posterior temporal muscle fibers are expected to be minimal considering its short moment arm length (Smith, 1984). It could be postulated that the posterior temporal muscle activity recorded during clenching in the presence of the unstable biting contact served the purpose of stabilization.

The moment arm length of the anterior temporal muscle is in between that of the masseter and the posterior temporal muscles (Smith, 1984). The anterior temporal muscle activity under the unstable contact could be due in part, to stabilization of the jaw and in part to the requirements of generating biting forces.

The provision of mandibular stability under unstable contacts by masticatory muscle recruitment seems to depend upon the direction and position of the biting forces, i.e., the direction towards which the unstable occlusal contact tends to shift the mandible, and the anteroposterior location on the tooth row (Smith, 1984). Under the conditions of this experiment in which the subjects were clenching in the RCP and not allowed to come forward into the IP, the masseter muscle inhibition was always present regardless of the direction and position of the biting forces. In the posterior temporal and anterior temporal muscles the right and left muscle activity seemed to depend upon the direction and position of the unstable contact on the tooth row. A tendency towards lateral asymmetry was noted and seemed to be explained by the moments generated around the biting contact. In general, biting contacts that tended to generate a clockwise moment on the frontal plane of the mandible were counterbalanced by both a posterior temporal and anterior temporal asymmetrical activity that tended to generate a counterclockwise moment in the mandible around the biting contact (see Figure 10). When the dentition was stabilized in the RCP through the use of a splint, there was a recovery in the masseter muscle activity and symmetry in the anterior temporal and posterior temporal muscle activity (see Figure 10).

The distortion of masticatory muscle activity under abnormal contact position has been previously reported by Pruzansky (1960), Møller (1975), Bakke and Møller (1980), and Freesmyer and Mans (1985).

The specific effects of occlusal disturbances in the development of TMJ disorders are not well understood (Bush, 1982; Zarb, 1985). Møller et al (1984) pointed out that a discrepancy between the IP position and the "ideal structural position" can produce muscular hyperactivity and thereby, induce dysfunction of the masticatory apparatus. He demonstrated that stabilization of the occlusion by occlusal adjustment facilitated blood flow in the masticatory muscles.

Unfavorable occlusal contact relations have been thought to lead to avoidance responses protecting the masticatory apparatus (Storey, 1975). The central nervous system(CNS) seems to play an important role in modulating the response of the masticatory apparatus under conditions of detrimental occlusal contact (Dubner, Sessle, and Storey, 1978). Protective jaw reflexes were abolished by electrical stimulation of CNS areas, such as the limbic brain (Achari and Thexton, 1972). In this study, jaw protective reflexes diminished the possible deleterious effect of occlusal instability by inhibiting masseter muscle activity. It could be speculated that, if by CNS modulation there is inhibition of jaw protective reflexes in a situation of occlusal instability resembling that in this experiment, the damage effected in the masticatory apparatus could be significant.

It seems that the masticatory musculature is poorly designed to cope with the unstable occlusal contacts that were present in this study. If the neuromuscular system is organized to minimize condylar load (Smith, 1984) and there is a need for the exertion of biting forces, the most beneficial way of dealing with the instability observed in the RCP may be the avoidance of the premature contact through an asymmetrical compensating shift in mandibular position. Under such conditions the best occlusal relationship may supercede the best TMJ relationship. This asymmetrical compensatory shift in mandibular position may constitute a strain on the TMJ structures that in the long term may be a factor in the initiation of TMD (Ramjford and Ash, 1983).

Ramfjord (1961) has shown that occlusal interferences in the RCP disturbed the EMG contraction patterns during swallowing. Removal of these interferences led to harmony in the muscle activity during swallowing. Telemetric studies conducted with the object of ascertaining the occlusal position at the end of the chewing and swallowing stroke revealed that the majority of gliding contacts were around the IP but some gliding contacts approached the RCP (Glickman, et al 1969; Glickman, et al 1974). It is now known that the mandible during chewing, prior to entering the IP, moves posteriorly. This posterior thrust of the mandible was described early by McCollum and Stuart (1955). Hickey et al (1963), and Lundeen and Gibbs (1982) have confirmed that the working condyle is at a posterior lateral position prior to the teeth entering the IP.

The importance of stability within a well-balanced straight slide forward from RCP to IP has been expressed by Dawson (1974) and Ramfjord and Ash (1983). A freedom of movement from RCP to IP is claimed to provide harmony in the TMJ and muscles. The means to achieve stability could range from an occlusal scheme that allows some freedom around the IP, like that obtained through natural occlusal wear (Beyron, 1964), occlusal adjustment (Ramfjord and Ash, 1983), occlusal splint therapy (Zarb and Speck, 1979), or rehabilitation with freedom in centric (Schuyler, 1969) to rehabilitation in IP coincident with RCP (McCollum and Stuart, 1955). The potential adverse effects of the last alternative are presented in the second part of the discussion.

The receptors monitoring stability are unknown (Storey, 1981). Bakke et al (1980) found that the activity of the anterior temporal and masseter muscles was positively related to the extent of occlusal contact. They suggested that the muscle activity was modified by periodontal receptors. As part of this investigation one subject was studied to explore the changes in muscular behaviour during clenching in the RCP with unstable contact, before and after anesthesia of the maxillary and mandibular teeth involved in the unstable contact. Prilocaine (Hcl 4%) Citanest plain (Astra Pharmaceuticals, Ontario, Canada, L4Y 1M4) was infiltrated around the maxillary tooth palatally and labially. For the mandibular tooth, blocking of the mandibular dental nerve was performed. There was no change in the muscular behaviour before and after anesthesia: periodontal receptors do not appear to be responsible for the masseter inhibition in the RCP. It seems reasonable to speculate that the receptors monitoring stability are variously located (joints, muscles, periosteum, periodontium, and ligaments) and integrated to determine the presence or lack of stability. The periodontal input may not be significant or the absence of input of one of the receptors may not affect the muscular response if other inputs are able to compensate for the loss.

B. The Retruded Contact Position (RCP) as an Ideal Position for Maximal Intercuspation

As the RCP was a reproducible position, when used for procedures involving rehabilitation of the dentition (McCollum and Stuart, 1955) it led to the general conclusion that it was the ideal position for the intercuspation of rehabilitated and natural dentitions.

Many authors expressed theoretical reservations with respect to the RCP as the ideal position (Brill, 1959; Atwood, 1968; Celenza, 1973; Gilboe, 1983).

Telemetric studies (Glickman et al 1969; Glickman et al 1974) and functional movement studies (Gibbs and Lundeen, 1982) have shown that the position of most functional use at the end of the chewing stroke is not the RCP. Ingervall (1964) in an epidemiological study found that a sample of 65 normal occlusion subjects had a mean RCP-IP distance of 0.89 mm.

Earlier studies that compared the muscle activity in the RCP to the IP came to the conclusion that the RCP was not an ideal position. Buxbaum et al (1982) found hyperactivity of the anterior temporal muscle in the RCP and concluded that this hyperactivity was not beneficial for the TMJ. Duthie and Yemm (1982) and Mahan et al (1983) found a diminution of masseter activity in the RCP. Mahan et al (1983) inferred that the TMJ appeared to be protected from loading in the RCP. Boos (1943) in a study of biting forces in different jaw registration positions in denture subjects using an intraoral gnathodynamometer found that in 32% of the cases the greatest force was not in the vicinity of the RCP.

In the current study, when comparing the mean activity in microvolts by muscle and position, the lowest masseter muscle activity and the highest anterior temporal and posterior temporal muscle activity were present in the RCP (see Table VIII). If the relationship of the masticatory muscles is analyzed by the use of a ratio which is assumed to represent the interaction between biting and positioning muscles (i.e., M/PT ratio), the RCP showed the lowest ratio (see Table X). This is interpreted to mean that in the RCP the masticatory apparatus requires more positioning muscle activity (posterior temporal) and limits biting muscle activity (masseter muscle). This was particularly evident during partial clenching (see Table XIII). It may be that full clenching overrides the protective reflexes operative in partial clenching. The significant increase in the posterior temporal muscle activity during partial clenching in the RCP could be due to the retrusive involvement of this muscle in positioning the mandible in the RCP. The significant increase in the anterior temporal muscle activity during partial clenching in the RCP could be due to a response of the system to reduce the pressure exerted by the condyles on the retrodiscal pad of the TMJ disc which is highly innervated and vascularized (Mohl, 1982).

In the present study, the mean masseter muscle activity (for all three groups) during full clenching was significantly lower in the RCP than in the IP and MP positions (see Table VII). The dual bite group had a severely reduced masseter muscle activity during full clenching in the RCP (see Table VI and Figure 9). Based on the assumption that the neuromuscular system is organized to minimize condylar loads (Smith, 1984), the RCP does not seem to be an ideal position for condylar loading. The significant decrease in the masseter muscle activity could be due to an excessively dorsal position of the condyles in the RCP in dual bite subjects.

Celenza (1973) observed the return of the RCP-IP distance in patients restored under the gnathological tenants of maximal intercuspation in the RCP. Since it seems that bone loading characteristics influence the behaviour of cells which maintain or alter the shape and organization of the bones (Cowin et al, 1984) it could be hypothesised that the joint remodelling inferred by Celenza (1973) could have been the response of the TMJ structures to hyperactive anterior and posterior temporal muscles.

It is a universal concept in physiotherapy that to maintain normal joint function, joint surfaces must be able to be moved passively by an examiner a few millimeters beyond the subject's voluntary range of motion. These small motions are called accessory movements or joint play (Mennell, 1964; Maitland, 1977; Lehmkuhl and Smith, 1983). It may be that the anterior temporal and posterior temporal muscles reactive hyperactivity in the RCP is the response of the masticatory system to retain normal joint function through remodelling of joint surfaces in an environment which has affected the normal joint range of motion. Adaptive remodelling changes in the TMJ to distal displacement of the mandible in monkeys have been reported by Ramfjord and Hiniker (1966) and Joho (1973).

There has not been any report of the incidence of TMD in patients that have been restored in the RCP. Since Celenza

(1973) observed anteroposterior adaptation of patients restored gnathologically, it could be postulated that in spite of the rehabilitation of patients in the less physiological RCP, there may be long-term adaptation. This may explain the clinical success claimed by gnathologists (McCollum and Stuart, 1955).

C. Muscular Activity as a Function of Anteroposterior Changes of the Mandible (IP and MP)

Clinically, the ideal condylar position of the mandible for intercuspation was regarded as a precise point contact (McCollum, 1927; Dawson, 1985). Various authors have expressed scepticism of this concept (Schuyler, 1969; Moss, 1975; Harvold, 1975).

Williamson (1978), in a laminographic study of the TMJ, when recording the condylar position with a leaf gauge, showed random anteroposterior intraindividual variability.

An area of freedom around the ideal jaw registration position seems to be compatible with the harmonious function of the masticatory apparatus (Ramfjord and Ash, 1983).

In this study, the mean masseter, anterior temporal, and posterior temporal muscles activity was not significantly different during clenching in the IP and MP positions (see

Table VIII). The ratio of the mean masseter muscle activity to the mean posterior temporal muscle acivity (M/PT ratio) was not significantly different during clenching in the IP and MP positions (see Table XII).

In the control group, the mean change in the condylar position along the X axis from the IP to the MP position, 0.33 mm, did not affect significantly the muscular behaviour (see Tables VI and XIII and Figures 6 and 7).

The fact that in the control group there was not a significant EMG difference between the IP and MP positions, suggests that either of these methods of obtaining occlusal registrations would be acceptable whenever normal occlusion, a sufficient number of natural teeth, and healthy TMJ structures are present.

This research does not propound the utilization of the MP registration employed in this study as the sole ideal registration position. Rather, it reconciles some of the previous structuralistic and functionalistic conceptualisations of the ideal registration position, since it shows that small differences in jaw position are not critical to the masticatory apparatus provided that there is good intercuspation. It agrees with the structuralistic idea that the precision of the occlusion is more important than the position (Celenza, 1973). It concurs with the structuralistic theory that proposes the uppermost and foremost as the ideal condylar position for intercuspation (Dawson, 1985), and with the functionalistic theory that proposed involvement of the muscular activity in defining the ideal mandibular position (Moyers, 1973).

It seems that, within a biologically acceptable range of variability in the mandibular position, there is no significant alteration in the muscular activity as long as there is even distribution of occlusal contact.

An area of freedom in centric up to 0.8 mm has been suggested to be within the adaptive range of most patients (Ramfjord and Ash, 1983).

D. Muscular Activity in Angle's Class II Division 2 Malocclusion

1. Muscle activity during full clenching

The class II division 2 group showed the highest masseter muscle activity during full clenching in the IP (see Table VI). Several studies have attempted to correlate facial architecture and muscle function. Weijs and Hillen (1984) assessed the cross-sectional area of the masticatory muscles by computerized tomography. They found larger cross-sectional areas of the masseter and medial pterygoid muscles in subjects with short faces and small gonial angles.

A correlation between maximal mean voltage in the masseter and a small gonial angle has been reported by Ahlgren (1966) and Møller (1966). Ringqvst (1973), in a study of the relationships between the facial skeleton and bite forces, found a correlation between high bite forces and a low mandibular plane angle. Ingervall and Thilander (1974) assessed the relationship of facial morphology and activity of the masticatory muscles. They found the highest EMG amplitudes in cases with a tendency to parallelism of the occlusal plane and mandibular plane.

Cephalometric studies generate controversies with respect to the craniofacial features of the class II division 2 malocclusion. Hitchcock (1976) and Maj and Lucchese (1982) demonstrated a tendency toward small gonial angle and low mandibular plane angle. On the other hand, Cleall and Begole (1982) found no difference between the craniofacial architecture of class II division 2 subjects when compared to class I normal occlusion subjects.

In the present study, lateral cephalograms from the class II division 2 subjects were available. Although there was a trend toward a low mandibular plane angle (mean mandibular plane to sella nasion angle = 26.7 degrees, in comparison to the mean of the Manitoba cephalometric analysis = 32 degrees), individual variations in the maximal masseter activity did not always correlate with the mandibular plane angle. Other factors, such as the extent of intercuspation and/or the musculoskeletal relations, may have accounted for the variations in the maximal masseter EMG activity.

2. EMG changes from the RCP to the IP

In the class II division 2 group, the mean anterior and posterior temporal muscle activity during partial clenching did not significantly decrease when the mandible moved from RCP to IP as it did in the control group (see Figures 7 and 8). In other words, there was a hyperactivity of the posterior temporal and anterior temporal muscles during partial clenching in the IP in the class II division 2 group when compared to the control group (see Table VI).

Posterior displacement of the mandible in class II division 2 malocclusion has been claimed by Rickets (1953), Grewcock and Ballard (1954), Perry (1960), and Graber (1966).

Møller (1966) found strong activity in the posterior temporal muscle associated with retroclination of upper incisors and a large overbite.

Eriksson and Hunter (1985) in a cephalometric study, found that treatment of a deep bite and retroclined incisors in class II division 2 malocclusion enhances mandibular growth and/or forward respositioning of the mandible.

However, Ingervall (1968) in a cephalometric study of the anteroposterior distance between the RCP and IP in class II division 2 subjects, found no evidence to support claims of a dorsally locked mandible in the IP. In this study there was no significant difference in the RCP-IP distance between the class II division 2 group and the control group, but there was a significant difference between these two groups in the overbite relationships.

It could be speculated from the findings of this study that the hyperactivity of the anterior temporal and posterior temporal muscles is related to the deep bite and retroclination of maxillary incisors that may have forced the mandible into a more dorsal intercuspation. The fact that the RCP-IP distance was not significantly different between the class II division 2 and control group, could be explained by TMJ remodelling. The hyperactivity of the anterior temporal and posterior temporal muscles may have induced remodelling in the TMJ structures in order to retain a normal range of motion. This hyperactivity may contribute to some types of TMD. Further studies are needed to evaluate the changes in EMG activity of masticatory muscles in orthodontically treated class II division 2 subjects.

That the class II division 2 subjects may be trying to overcome the dorsally placed mandibular position could also be supported by the EMG activity during clenching in the MP position. The MP position was, on the average, 0.37 mm ahead of the IP position (see Table IV). There was a significantly lower anterior temporal and posterior temporal muscles activity during partial clenching in the MP than in the RCP and IP (see Table VI). These seemed to resemble the changes in the control group from the RCP to the IP and MP positions.

E. Muscular Activity in the Dual Bite Malocclusion

The dual bite is a condition of special interest to clinicians engaged in the treatment of malocclusions. A dual malocclusion is defined as an occlusion with an abnormally long, (more than 2 mm) anteroposterior difference between the RCP and IP (Ingervall, 1979). Schweitzer (1962), in a functional movement study of chewing in dual bite subjects, showed that the greatest proportion of the masticatory cycles was carried out anterior to the RCP but not as far forward as the anterior IP.

EMG studies have documented the muscular activity in different occlusal positions of dual bite subjects (Ingervall, 1979; Tallgren et al, 1979). The main conclusion of these studies was that even though the dual bite subjects seemed to prefer the most forward IP position, they showed a "better" EMG (i.e., higher muscular activity) in the posterior intercuspal position. These findings have been interpreted to mean that the ideal treatment position for the dual bite malocclusion should be in or close to the RCP position.

In this study the dual bite group had a significantly lower mean masseter muscle activity during full clenching in the RCP than in the IP and MP positions (see Figure 9). Furthermore, this mean masseter muscle activity during full clenching in the RCP was the lowest between groups (see Table VI). In the same way, the dual bite group had a significantly lower M/PT ratio in the RCP than in the IP and MP positions. This M/PT ratio in the RCP was the lowest between groups (see Table XI).

The aforementioned findings could be interpreted to mean that the RCP is not an ideal position for intercuspation in the dual bite group. The dual bite group seemed to be more prone to muscular inhibition while clenching in the RCP than the other groups. This suggests an unfavourable relationship of the TMJ structures in the dual bite group in the RCP.

On the assumption that the neuromuscular system is organized to minimize condylar load (Smith, 1984), the RCP does not seem to be an ideal position for condylar loading, especially in the dual bite group. On the evidence presented by this research, it could be concluded that the treatment of a dual bite malocclusion should not be aimed at stabilizing the occlusion in the RCP.

In this study, the EMG activity in the dual bite group in the IP and MP positions differed significantly. The M/PT ratio was significantly lower in the MP than in the IP position (see Table XI). The M/PT ratio of the dual bute group in the MP position was the closest to the IP and MP ratios of the control group.

SUMMARY AND CONCLUSIONS

The electrical activity of masticatory muscles during full and partial clenching in three mandibular bite registration positions was studied (retruded contact position, intercuspal position, and muscular position). Three groups of subjects with different ranges of anteroposterior positioning of the condyles were evaluated (control group, class II division 2 group, and dual bite group). Records were made with and without standardization of the distribution of occlusal contact. The linear envelope EMG signal from three bilateral muscles was recorded (masseter, anterior temporal, and posterior temporal). Data was analyzed utilizing a Mixed Analysis of Variance.

Clenching in the retruded contact position without splint and with the presence of an unstable occlusal contact inhibited the masseter muscle activity and reduced asymmetrically both the anterior temporal and posterior temporal muscular activity. The masticatory muscle activity returned to normal when clenching in the retruded contact position with a splint that permitted stability in the dentition. The main occlusal determinant of maximal masseter isometric muscle contraction seems to be the uniform distribution of tooth contact. If the dentition takes the major role of stabilizing the mandible, i.e., there is good intercuspation, the masseter muscle can exert maximal isometric contractions. If the stability is not provided in the dentition, i.e., there is a premature contact, the jaw muscles should stabilize the mandible as well as provide the biting force. Under such conditions, the potential masseter biting activity is considerably reduced, possibly to avoid damage to the structures involved in the compensatory stabilization. The receptors monitoring stability seem to be variously located (joints, muscles, periosteum, periodontium, and ligaments) and integrated to determine the presence or lack of stability.

Clenching in the retruded contact position with a splint elicited the lowest masseter muscle activity, and the highest anterior temporal and posterior temporal muscle activity. If the relationship of the masticatory muscles is analyzed by the use of a ratio which is assumed to represent the interaction between biting and positioning muscles, i.e., masseter to posterior temporal muscle ratio, the RCP showed the lowest ratio. In the retruded contact position the masticatory apparatus required more positioning muscle activity (posterior temporal) and permitted less biting muscle activity (masseter). The significant decrease in the masseter muscle activity could be due to a response of the system to reduce the pressure exerted by the condyles on the retrodiscal pad of the TMJ disc. The significant increase in the posterior temporal muscle activity could be due to the retrusive involvement of this muscle in positioning the mandible in the retruded contact position. The significant increase in the anterior temporal muscle activity could be due to a response of the system to reduce the pressure exerted by the condyles on the retrodiscal pad of the TMJ disc. It seems that the retruded contact position is not an ideal position for intercuspation.

In the control group, there was no significant difference in the mean masseter, anterior temporal, and posterior temporal muscles activity during clenching in the intercuspal and muscular positions. The ratio of the mean masseter muscle activity to the mean posterior temporal muscle activity was not significantly different during clenching in the intercuspal and muscular positions. This suggests that in normal occlusion subjects, with a sufficient number of natural teeth and healthy TMJ structures, either the intercuspal or the muscular registration position is biologically acceptable. Small changes in jaw position are not critical for the masticatory apparatus provided that there is good intercuspation. It seems that in a biologically acceptable range of variability in the condylar position, there is no significant alteration in the muscular activity as long as there is even distribution of occlusal contact.

The class II division 2 malocclusion group showed the highest masseter muscle activity during full clenching. Although there was a trend in the facial architecture of the class II division 2 subjects towards a flat mandibular plane, there were individual variations in the maximal masseter muscle activity not always related to the changes in the mandibular plane angle. Other factors, such as the extent of intercuspation and/or the musculoskeletal relations, may account for the variations in the maximal masseter EMG activity.

The class II division 2 subjects showed a hyperactivity of the posterior temporal and anterior temporal muscles during partial clenching in the intercuspal position when compared to the control group. This hyperactivity could be related to the deep bite and retroclination of maxillary incisors that may have forced the mandible into a more dorsal intercuspation.

The dual bite subjects had a significantly lower mean masseter muscle activity ratio in the retruded contact position. These muscle activity features in the retruded contact position in the dual bite subjects were the lowest between groups. The retruded contact position does not seem to be an ideal position for intercuspation in the dual bite group.

Future Research Recommendations:

A. The following projects would further clarify the neuromuscular control of mandibular stability.

The unstable contact usually present in the retruded contact position could be used to confirm the predictions of the muscle compensations under unstable contact obtained with the numerical model developed by Smith (1984). This requires the development of tools to measure the magnitude, direction, and point of application of the force produced during clenching with the unstable contact. If so, EMG human studies could be carried out to ascertain the relations between the predicted and actual muscle compensations.

Human EMG studies should be carried out before and after blocking of the receptors postulated to be involved in the perception of mandibular stability. Anesthesia of the TMJ and/or vibration of the masticatory muscles in normal and in denture subjects while clenching in an unstable contact could be employed.

Ideally, an animal model should be developed to explore the receptors, pathways, and modulation of mandibular stability. Human studies, if possible, and animal experiments should be developed to explore the role of CNS factors in monitoring the peripheral response to abnormal dental contacts. Short-term and long-term modifications in the muscular behaviour during clenching in unstable dental contacts under psychological stress-induced situations could be studied.

B. The following projects would further clarify the muscular adaptations to changes in anteroposterior positioning of the mandible in occlusal contact.

1. short-term and long-term EMG studies during treatment of patients restored under gnathological tenets.

2. epidemiological studies of the incidence of TMD in gnathologically restored patients.

3. human EMG studies in patients with full mouth rehabilitation or dentures should be carried out to observe the short- and long-term muscular adaptations to anteroposterior changes of the mandible in full

intercuspation. This study should ideally include the recording of the lateral pterygoid muscle and should involve, beside clenching, swallowing and chewing activities.

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APPENDIX

This appendix includes the tables of the data used in the error studies and tables of comparisons not included in the body of the thesis.

TABLE Ia

Calculation of maximum errors associated with the Buhnergraph method on the X and Y axes in mm.

Subject	Side	Repeated measures on the X axis	Repeated measures on the Y axis
1	Right	0, 0, 0	0, 0, 0
	Left	0, 0.1, 0	0. 0.1, 0
2	Right	0, 0, 0	0, 0, 0
	Left	0, 0, 0.1	0, 0, 0.1
3	Right	0, 0, 0	0, 0, 0
	Left	0, 0, 0	0, 0, 0.1
$\Sigma\Sigma(X-\bar{X})^2$		.02	.03
Sd of error		.04	.05
Maximum error associated with 99% of measurements		.122	.152

TABLE IIa

Calculation of maximum errors associated with the RCP registration on the X and Y axes in mm. (+).

Repeated Measures

Subject	Side	on the X axis	on the Y axis
1	Right	.3, .3, .3	.9, .9, .9
	Left	.6, .6, .5	.4, .5, .4
2	Right	.5, .5, .4	1.0, 1.0, 1.0
	Left	.6, .6, .6	1.2, 1.3, 1.2
3	Right	.8, .8, .8	.2, .2, .3
	Left	1.0, .9, 1.0	.3, .2, .3
$\Sigma\Sigma(X-\bar{X})^2$		.03	.04
Sd of error		.050	.057
Maximum error associated with 99% of measurements		.152	.174

(+) Measures show the RCP-IP distance.

TABLE IIIa

Calculation of maximum errors associated with the MP registration on the X and Y axes in mm. (+).

Subject	Side	Repeated Measures on the X axis	Repeated Measures on the Y axis
1	Right	.8, 1.0, 1.0	.0, .2, .2
	Left	.8, .8, 1.0	.2, .2, .3
2	Right	.3, .4, .4	.3, .1, .1
	Left	.6, .8, .7	.2, .1, .0
3	Right	.5, .5, .8	1.1, 1.1, 1.5
	Left	.7, .7, .9	1.0, 1.0, 1.3
$\Sigma\Sigma(X-\bar{X})^2$		.18	.26
Sd of error		.12	.14
Maximum error associated with 99% of measurements		.366	.427

(+) Measures show the RCP-MP distance.

TABLE IVa

Calculation of maximum errors associated with the splint distortion along the X and Y axes in mm (+).

Repeated Measurements

Side	on the X axis	on the Y axis
Right	.1, .1, .1, .1, .1, .1	.3, .1, .2, .2, .2, .3
Left	.0, .1, .1, .1, .1, .0	.6, .6, .5, .5, .5. .6
$\Sigma\Sigma(X-\bar{X})^2$	.02	.08
Sd of error	.04	.08
Maximum error associated with 99% of measurements	.126	.253

TABLE Va

Calculation of maximum errors of electromyographical peak and average amplitude on the masseter muscle in microvolts.

Repeated Recordings

Subjects	Full clenching	Partial clenching
1	375, 362, 362	50, 50, 45
2	300, 237, 275	50, 50, 45
3	575, 575, 550	50, 50, 37
4	150, 162, 162	50, 45, 45
5	425, 425, 400	100, 100, 75
6	325, 262, 300	25, 25, 25
7	537, 475, 525	62, 62, 55
8	362, 350, 325	37, 37, 37
9	325, 400, 387	37, 37, 37
10	300, 250, 250	12, 12, 12
$\Sigma\Sigma(X-\bar{X})^2$	12821.988	612.0
Sd of error	25.32	5.532
Maximum error associated with 99% of measurements	72.0354	15.738

TABLE VIa

Means of masseter muscle activity in microvolts for two positions and for the right and left sides.

Position	Right	Left
IP	469	401
MP	472	420

No significant difference could be detected.

TABLE VIIa

Muscle activity during full clenching in the RCP with and and without splint for all subjects (Raw EMG data in microvolts).

	Subjects	Masseter S	Masseter N	Anterior Temporal S	Anterior Temporal N	Posterior Temporal S	Posterior Temporal N
Control group	1	655	0	755	165	653	303
	2	938	25	1335	268	750	260
	2	1105	0	1128	238	1025	375
	4	243	25	995	190	380	200
	5	660	0	1233	313	448	333
	6	368	0	1063	200	908	400
	7	1318	10	980	80	1533	558
	8	325	10	670	100	553	263
	9	490	38	715	355	920	120
	10	678	87	1038	243	1010	478
	11	733	25	1275	608	733	445
	12	355	25	345	273	540	398
Class II division 2	13	255	0	400	250	525	650
	14	830	825	700	575	645	625
	15	845	25	750	575	635	500
	16	1398	25	1125	95	873	990
	17	533	237	1098	723	835	528
	18	680	50	1163	673	1015	695
	19	758	0	1125	73	1335	500
	20	583	25	993	450	683	480
	21	1955	112	1398	443	1173	450
	22	1093	12	1343	455	1013	488
	23	1018	75	1118	95	785	215
	24	810	25	778	343	403	215
	25	1003	25	913	175	718	375
	26	2280	150	1308	488	1130	578
Dual bite group	27	118	0	353	140	100	30
	28	423	50	955	533	510	430
	29	373	0	648	43	438	213
	30	568	25	840	333	623	490
	31	463	17	490	165	513	365
	32	395	0	888	163	780	363
	33	273	50	675	440	450	348
	34	110	75	675	433	285	223
	35	190	12	673	308	600	288
	36	30	0	438	220	755	578
	37	608	37	708	210	895	695

S: Splint

N: No splint

TABLE VIIIa

Comparison of mean activity in microvolts by group, position, and activity (means are for all three pairs of muscles, splint only). (+)

	RCP		IP		MP		
Groups	Full	Partial	Full	Partial	Full	Partial	Se (+)
Control	723	86	728	45	757	47	1.088
Class II division 2	880	103	917	92	858	71	1.081
Dual bite	426	105	469	44	554	44	1.091

(+) Retransformed data. Standard errors are applied to means multiplicatively.

TABLE IXa

Comparison of mean activity in microvolts by position and activity (means are for all three groups and all three pairs of muscles , splint only). (+)

Positions	Full	Partial	Se(+)
RCP	647	98	1.049
IP	679	57	1.049
MP	711	53	1.049

(+) Retransformed data. Standard errors are applied to means multiplicatively.

TABLE Xa

Comparison of mean activity in microvolts by position (means are for all three groups, all three pairs of muscles, and both activity levels, splint only). (+)

Positions	Microvolts	Se (+)
RCP	252	1.013
IP	198	1.013
MP	196	1.013

(+) Retransformed data. Standard errors are applied to means multiplicatively.

TABLE XIa

Comparison of mean activity in microvolts by group (means are for all three pairs of muscles, all three positions, and both activity levels, splint only). (+)

Groups	Microvolts	Se (+)
Control	206	1.101
Class II division II	279	1.093
Dual bite	170	1.104

(+) Retransformed data. Standard errors are applied to means multiplicatively.

TABLE XIIa

Comparison of variable 7 (sum of the mean masseter, anterior temporal, and posterior temporal muscle activity, in microvolts) by position and splint (means are for all three groups, full clenching only). (+)

Position	With splint	Without splint	Se (+)
RCP	2069	668	1.049
IP	2151	2017	1.049

(+) Retransformed data. Standard errors are applied to means multiplicatively.

TABLE XIIIa

Comparison of variable 8 (ratio of the mean activity of each individual muscle without a splint to that with a splint, NS/S ratio) by muscle (means are for all three groups and two positions, full clenching only). (+)

Muscle	NS/S ratio	Se (+)
Masseter	0.402	1.013
Anterior temporal	0.629	1.013
Posterior temporal	0.845	1.013

(+) Retransformed data. Standard errors are applied to means multiplicatively.

TABLE XIVa

Comparison of variable 2 [ratio of the sum of the mean activity of masseter and anterior temporal muscle to posterior temporal muscle, (M + AT)/PT] by group and position (means are for both activity levels, splint only). (+)

Group	RCP	IP	MP	Se (+)
Control	3.255	4.236	4.370	1.061
Class II division 2	2.845	3.073	3.518	1.056
Dual bite	2.176	6.533	4.649	1.066

(+) Retransformed data. Standard errors are applied to means multiplicatively.

TABLE XVa

Comparison of variable 2 [ratio of the sum of the mean activity of masseter and anterior temporal muscle to posterior temporal muscle, (M + AT)/PT] by position and activity (means are for all three groups, splint only). (+)

Position	Full	Partial	Se (+)
RCP	2.133	3.446	1.047
IP	2.953	6.464	1.047
MP	2.837	5.918	1.047

(+) Retransformed data. Standard errors are applied to means multiplicatively.

TABLE XVIa

Comparison of variable 2 [ratio of the sum of the mean activity of masseter and anterior temporal muscle to posterior temporal muscle, (M + AT/PT] by position and splint (means are for all three groups, full clenching only). (+)

Position	With splint	Without splint	$Se^{(+)}$
RCP	2.133	0.940	1.044
IP	2.953	2.334	1.044

(+) Retransformed data. Standard errors are applied to means multiplicatively.