Integrated Electromyography of the Masseter on Incremental Opening and Closing with Audio Biofeedback: A Study on Mandibular Posture

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Purpose: The purpose of this study was to test the hypothesis of a minimum electromyographic (EMG) rest position based on masseter surface EMG recordings of incremental opening and closing of the mandible with simultaneous audio EMG biofeedback. **Materials and Methods:** Nineteen alert subjects in an upright seated position opened and closed the mandible in 1-mm increments 20 mm interincisally. An electronic recording device allowed each subject to maintain the vertical dimension of each increment while simultaneously reducing right masseteric muscle activity to the minimum possible level using audio EMG biofeedback. Integrated EMG masseteric activity was recorded at each static opening and closing increment. **Results:** A mean plateau of integrated EMG output for all subjects with no minimum EMG point or circumscribed minimum EMG range for any of the nineteen subjects was shown. Analysis of variance for repeated measures showed no difference in opening and closing EMG levels ($P = 0.27$) and no interaction between opening, closing, and change in vertical dimension ($P < 0.0001$). **Conclusion:** These results, with those of other studies, raise questions regarding the validity of the concept of a unique physiologic rest position of the mandible with the masseter or associated muscles at minimum muscle activity. The idea of overlapping postural ranges appears to be more appropriate. *Int J Prosthodont 1999;12:419–425.*

The postural rest position of the mandible continues to be used as a vertical reference relation for restoring the occlusal vertical dimension in prosthodontics.

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However, controversy remains regarding the ability to define and clinically measure a repeatable postural relation that fits this role. Mandibular posture occurs at multiple possible instantaneous positions constantly moving in response to such factors as changes in posture, respiration, swallowing, pressure, lip competence, and speech.[1]

Physiologic rest position, as defined in *The Glossary of Prosthodontic Terms,* occurs when the associated musculature is in a state of tonic equilibrium or minimal contractural activity.[2] This assumes that physiologic rest position is a specific position and that there is a single position of minimum tonic elevator contractural activity. There has been disagreement as to whether minimum electric activity occurs at a specific jaw separation or over a range of vertical heights.[3]

Physiologic rest position is thought to be distinct from the more cranially related clinical rest position, a repeatable clinical reference relation with an

Table 1 Vertical Mandibular Relations and Ranges Reported in the Literature for Dentate Subjects

Study	No. of subjects	Interocclusal rest space (mm)			Method	
Clinical rest position						
Garnick and Ramfjord 1962[4]	20	1.7 ± 1.28			Command, phonetic, swallowing	→ NHR, EO, MD
Rugh and Drago 1981[7]	10	2.1			Phonetics	→ NHR, EO ✱
Wessberg et al 1983[8]	4	2.5 ± 1.2			Phonetics	↑NHR, EO ✱
Peterson et al 1983[9]	10	4.6 ± 1.42	Low mandibular plane angle		Phonetics	→ HR, EO ●
Peterson et al 1983[9]	10	3.2 ± 1.09	High mandibular plane angle		Phonetics	→ HR, EO ●
Van Sickles et al 1985[10]	12	3.2 ± 2.1	Long face		Phonetics	→ HR ●
Gross and Ormianer 1994[18]	8	2.6 ± 0.33			Command	→ HR, EO ✱
Michelotti et al 1997[23]	40	1.4 ± 1.1			Phonetics	→ HR, EO ●
Michelotti et al 1997[23]	8	2.0 ± 1.3	Low mandibular plane angle		Phonetics	→ HR, EO ●
Michelotti et al 1997[23]	8	0.8 ± 0.8	High mandibular plane angle		Phonetics	→ HR, EO ●
Minimum EMG rest position						
Rugh and Drago 1981[7]	10	8.6 (range 4.5–12.6)		NSF		→ NHR, EO ✱ § BFB
Manns et al 1981[12]	8	10		Masseter		→ HR, EC ● § ITR
Wessberg et al 1983[8]	4	5.3 ± 1.9		NSF	Mandible	↑ NHR, EO ✱ §
Peterson et al 1983[9]	10	9.7 ± 4.24	High mandibular plane angle	NSF	static on	→ EO ✱ § ITR
Peterson et al 1983[9]	10	9.95 ± 2.09	Low mandibular plane angle	NSF	incremental	→ EO ✱ § ITR
Van Sickles et al 1985[10]	12	10.1 ± 3.6	Opening sequence	NSF	opening or	→ HR, EO § ITR
Plesh et al 1988[14]	9	9.2 ± 3.9	Opening sequence	Masseter	closing	→ HR, EO ✱ § ITR
Plesh et al 1988[14]	9	11.9 ± 6.1	Closing sequence	Masseter	sequence	→ HR, EO ✱ § ITR
Plesh et al 1988[14]	9	6.1 ± 2.2	Opening sequence	NSF		→ HR, EO ✱ § ITR
Plesh et al 1988[14]	9	8.3 ± 3.5	Closing sequence	NSF		→ HR, EO ✱ § ITR
Michelotti et al 1997[23]	40	7.7 ± 2.7	Opening sequence	NSF		→ HR, EO ✱ § ITR
Minimum EMG resting range						
Manns et al 1981[12]	8	12.5 12–19	Opening sequence	Anterior temporal		→ HR, EC ● § ITR
Manns et al 1981[12]	8	15.5 6–18	Opening sequence	Posterior temporal	Mandible	→ HR, EC ● § ITR
Majewsky and Gale 1984[13]	22	4–16		Anterior temporal	static on	→ HR, EC, MD §
Majewsky and Gale 1984[13]	22	4–16		NSF	incremental	→ HR, EC, MD §
Plesh et al 1988[14]	9	10.8 ± 4.4	Opening sequence	Anterior temporal	opening or	→ HR, EO ✱ § ITR
Plesh et al 1988[14]	9	10.3 ± 4.4	Closing sequence	Anterior temporal	closing	→ HR, EO ✱ § ITR
Michelotti et al 1997[23]	40	4–18	Opening sequence	Masseter	sequence	→ HR, EO ✱ § ITR
Michelotti et al 1997[23]	40	4–18	Opening sequence	Anterior temporal		→ HR, EO ✱ § ITR
	19	1–19	Opening sequence	Masseter		→ HR, EO ✱ § BFB
Present study		1–19	Closing sequence	Masseter		→ HR, EO ✱ § BFB
Van Mens and de Vries 1984[17]	60	2.12 ± 0.74		Anterior temporal	Biofeedback	→ HR, EO ●
George and Boone 1979[15]	14	2.9				→ NHR ✱
Wessberg et al 1983[8]	4	5.2 ± 1.5			TENS-induced	↑ NHR, EO ✱
Konchak et al 1988[50]	62	2.6 ± 1.5 before TENS 3.4 ± 1.9 after TENS			rest position	→ HR, EO ✱
Gross and Ormianer 1994[18]	8	4.4 ± 0.67			Deep relaxation	→ HR. EO ✱ §
Ormianer and Gross control 1998[19]	8	3.1 ± 0.04			(relaxed resting posture)	→ HR, EO ✱ §
Manns et al 1990[16]	12	8.9			Hypnosis	→ HR, EO ●
Maximum bite force relation						
Storey 1962[22]	3	17.5				
Garrett et al 1964[54]		17–27	Constant bite force/minimum EMG			
Manns and Spreng 1977[55]		20			Maximum bite force relation	
Manns et al 1979[52]	8	15–20				
MacKenna and Turker 1983[57]		17				
Lindauer et al 1991[58]		15–20	Minimum EMG submaximal bite force			

→ = sitting erect; NHR = no headrest; EO = eyes open; MD = mechanical device measured interocclusal rest space; ✱ = electronic interocclusal rest space assessment; ↑ = standing erect; HR = headrest; ● = skin-point measurements; NSF = nonspecific facial muscles; § = incremental study; BFB = biofeedback relaxation at static increments; ITR = instructed to relax at static increments; EC = eyes closed; TENS = transcutaneous electric nerve stimulation.

interocclusal rest space (IORS) range of 1 to 4 mm (Table 1). Clinical rest position is registered immediately following cranial relation of the mandible by phonation, swallowing, or tooth closure.[3–11] As the musculature is further relaxed the mandible assumes a more open range of positions. Relaxed resting mandibular posture has been associated with a point or range of minimum electromyographic (EMG) activity,[7,12–14] as established with transcutaneous electric nerve stimulation (TENS),[8,15] hypnosis,[16] biofeedback,[17] and relaxation techniques.[18,19]

Findings of a vertical postural zone of suppressed elevator EMG activity during slow closure[4,20–22] and at static increments[7,12–14] suggest that physiologic rest position occurs within a postural range, the width of which varies among studies.[3,5,7,12,22] A circumscribed point of minimum surface EMG activity was reported for masseter and nonspecific facial muscles and termed the minimum EMG rest position (MERP).[7,9,10,12] Other studies have shown a minimum EMG resting range (MERR) for elevator muscles.[12–14,23] These ranges showed variations between opening and closing recording sequence and variations between different recording protocols (Table 1).

Difficulties have arisen in attempting to measure static postural positions of minimal muscle activity. To record minimum EMG activity at a particular vertical relation a spatial recording device is necessary to aid a subject in achieving and maintaining a desired degree of interocclusal separation. Using such a device the subject has to alternately activate depressors and elevators to maintain this vertical relation during recording of the EMG activity. While this is being done the mandible is not in a true relaxed resting relation. Attempts have been made to overcome this by prerecording relaxation training and by instruction to relax at each static increment.[9,10,12,14,23] Rugh and Drago[7] used simultaneous visual biofeedback with a kinesiograph oscilloscope.

A greater variation in the rest position following biofeedback has been reported by Van Mens and de Vries.[17] Mean published values of clinical rest position and MERR (Table 1) and a previous study[19] indicate that overlap often occurs between clinical rest position, MERR, and relaxed resting posture, suggesting that minimum masseter EMG may be independent of vertical dimension with suitable relaxation. If an effective relaxation technique is used at consecutive static or closing increments a subject should be able to reduce EMG levels to minimum levels for each postural relation. This is inconsistent with the notion of a unique minimum EMG rest vertical dimension.

The purpose of this study was to test the hypothesis of MERP based on surface masseter recordings by measuring masseteric EMG levels at successive 1-mm vertical opening and closing increments of mandibular posture, using both visual feedback to maintain the postural vertical relation and simultaneous audio EMG biofeedback to minimize EMG levels at each increment.

Materials and Methods

Subjects

On the basis of availability and compliance 19 dental students (12 men and 7 women, mean age 28) were selected. All had intact stable dentitions and were free of signs and symptoms of temporomandibular disorders. Exclusion criteria included sensitivity to digital pressure of right and left masseter and temporal muscles, lateral temporomandibular joint aspects, and limitations of movement or joint sounds.

Measurement System

Each subject was seated vertically and comfortably in a dental chair with a headrest and instructed to keep the eyes open and to look directly ahead. Surface bipolar electrodes (triple silver chloride electrodes, J & J Poulsbo) were adhered to the facial skin. Electrodes were placed over the right masseter in the general direction of the muscle fibers at a consistent position measured to be in the middle of the superficial part of the masseter at the level of the occlusal plane. The skin was cleaned with alcohol and electrode gel conductive paste was applied. The electrodes were connected to an EMG recording system (Atlas 8600, Physiolos) with an audio biofeedback channel. The EMG unit was connected to a computer capable of storing continuous EMG signals. The EMG recording equipment had a 0.25-μV root mean square noise level specified by the manufacturer with a 100- to 200-Hz bandpass. The 5-μV range was used to detect differences in the 1 to 2 μV range. The noise levels and bandpass of the equipment used by Rugh and Drago[7] were similar to those used in this study (Rugh JD, personal communication, 1989). The EMG unit is routinely used in research and clinical application and was regularly serviced to ensure reliability of the EMG output. Interocclusal rest space measurements were made using an IORS-recording device that has been previously described.[18] Subjects were able to depress and elevate the mandible and simultaneously observe the digital display to an accuracy of 0.001 mm.

Biofeedback Training and Recording

Before each recording session subjects were encouraged to relax and were trained to reduce the tone of the audio EMG channel to consistent minimum levels. When a minimum level of EMG activity was achieved repeatedly over 5 minutes it was recorded as the baseline minimum EMG level for that subject. This procedure was repeated 5 times and the mean value was recorded. Subjects then learned to depress and elevate the mandible in 1-mm increments using the visual digital display. They then learned to maintain each level of opening and to simultaneously reduce the audio EMG tone to a minimal level for 5 to 10 seconds at each increment. At the start of the recording sequence subjects were encouraged to relax using the audio feedback. When this reached the baseline EMG level the recording was initiated and marked on the screen at 3-second intervals. Subjects then lowered the mandible by 1 mm, holding this position using the visual digital recorder display and simultaneously reducing EMG tones to a

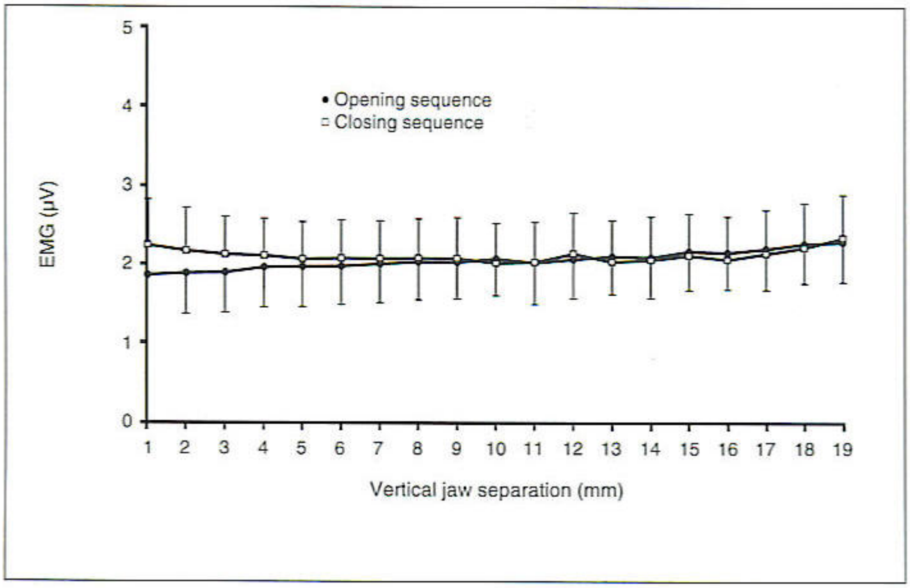

Fig 1 Mean integrated EMG values at static increments of vertical jaw separation with audio biofeedback. Vertical lines = standard deviation.

minimal level. The operator initiated the 3-second recording period when the digital positioning device reading stabilized at each increment. Consecutive 1-mm increments were recorded in an opening sequence up to an IORS of 20 mm followed immediately by a closing sequence in 1-mm increments back to intercuspation. The EMG data for each recording period were processed as the mean values with standard deviations for the consecutive readings in each 3-second recording interval.

Statistical analysis was carried out using analysis of variance (ANOVA) and covariance for repeated measures.

Results

Figure 1 shows the mean integrated masseteric EMG values for 19 subjects on incremental mandibular opening and closing. Both opening and closing graphs show a distinct plateau of masseteric EMG levels from intercuspation to 20 mm of opening for both opening and closing increments. There was no specific minimum point or range of suppressed EMG activity evident in any subject.

ANOVA for repeated measures showed no statistical difference in opening and closing (EMG, $P = 0.27$) and no interaction between opening, closing, and change in vertical dimension ($P = 0.45$). Mean opening and closing values were 2.08 ± 0.52 μV and 2.14 ± 0.5 μV, respectively. Mean baseline minimum EMG was 1.85 ± 0.87 μV, range 0.4 to 2.85 μV. For opening increments the recorded range between maximum and minimum values was 0.5 μV and 0.2 μV for closing increments.

These findings show no circumscribed minimum EMG point or range for 1-mm incremental opening and closing in any of the 19 subjects. The small EMG range of Δ 0.2 μV to Δ 0.5 μV showed the repeatability of EMG levels.

Discussion

The results of this study show a plateau of EMG values that is distinctly different from the point of minimum masseteric and facial EMG activity (MERP).[7,9,10,12] These results indicate that for the methodology used minimum masseteric muscle activity does not occur at a specific resting vertical dimension when effective masseteric muscle relaxation is achieved at measured increments.

Efforts to reproduce and measure the glossary-defined physiologic rest position[2] as a repeatable MERP correlating tonic resting elevator EMG activity with successive incremental vertical postural relations have shown conflicting and inconclusive results. A specific vertical relation of minimum integrated EMG (MERP) has been shown for the masseter and nonspecific facial muscles.[7,9,10,12] Noncircumscribed ranges of minimum EMG (MERR) have been reported for the anterior and posterior temporal muscles[14,23] and for the masseter.[23]

The anterior temporal has been described as the muscle most active and sensitive to changes in postural relations.[24,25] For the glossary definition of physiologic rest position to be valid, one would expect to see an MERP for the anterior temporal as well as for the masseter, which is not the case.[12,23]

Minimum EMG ranges of elevator muscles have been described during continuous slow opening and closing movements of the mandible.[4,20,21,26] Garnick and Ramfjord[4] report a range of minimum dynamic elevator activity during 11 mm of uninterrupted slow opening 3.8 mm from intercuspation. This was described as "a resting range" of the muscles during continuous slow movement and has often been misquoted as the postural resting range of the mandible, implying a range of static resting mandibular posture. Static incremental studies show both circumscribed points and noncircumscribed ranges of minimum EMG activity.[7,9,10,12–14,23]

With an electrode configuration recording nonspecific facial muscles a mean MERP of 8.6 mm on static opening increments (range 4.5 to 12.6 mm) was shown by Rugh and Drago.[7] Manns et al[12] report a circumscribed MERP of 10 mm for the masseter. Majewsky and Gale[13] show a noncircumscribed MERR for masseter and nonspecific facial muscles, while Michelotti et al[23] report an MERR for masseter and anterior temporal muscles (IORS) of 4 to 16 mm and MERP for nonspecific facial muscles. A significant difference in masseter MERP is reported by Plesh et al[14] between an opening sequence (IORS) at 5 mm and a closing sequence (IORS) at 15 mm. The same was seen for nonspecific facial muscles, indicating that MERP measured in this manner is subject to prior jaw motion. Minimum muscle activity also occurs at different vertical relations for different muscles.[12,14] Manns et al[12] report a minimum EMG point of 10 mm for the masseter, a minimum EMG range MERR at 13 mm of opening for the anterior temporal, and an MERR at 16 mm for the posterior temporal muscle.

Differences between our findings and those cited above may be caused by differences in relaxation protocol influencing the degree of control in muscle relaxation at each static increment. Manns et al[12] used no EMG relaxation feedback and no vertical positioning aids. Plesh et al[14] and Michelotti et al[23] used instructions for muscle relaxation and a kinesiograph for vertical positioning. Majewsky and Gale[13] used instructions to relax at increments and a mechanical vertical measuring device, while Rugh and Drago[7] used simultaneous visual feedback for relaxation and vertical positioning. The findings of Plesh et al[14] of the effects of prior jaw motion suggest that insufficient muscle relaxation occurs at sequential increments. The after effect of muscle spindles was used to explain the difference in EMG recordings and MERP between incremental opening and closing sequences.[14,27–31]

Biofeedback as used in the present study—acting via the limbic and fusimotor system—would act to reduce EMG activity to close to minimum baseline levels irrespective of the vertical dimension and prior jaw motion by inhibiting the overriding effects of gamma motor neurons on MERP.

The mechanism and level of minimum tonic resting EMG varies with mental status, affecting recording levels of mandibular posture. Taylor[32] attributed tonic baseline EMG to tonic stretch reflex unitary firing of Type I fibers in deep masseter and anterior temporal muscles, with background motor neuron excitation and tonic firing in the static fusimotor system. In sleep and during anesthesia contraction of the jaw elevator muscles is reduced or abolished as primarily the elastic forces of inert muscles and connective tissues[6,26,32–34] support the mandible. The level of tonic EMG activity can vary from minimal levels during general anesthesia, sleep, hypnosis, autogenic relaxation, biofeedback, or relaxation to relaxed or stressed vigilance.[6,11,16,19,32–37] Variations in body posture, eye closure, and environmental light levels reduce anterior temporalis and masseter resting EMG levels.[6,36,37] The validity of comparing normative EMG values[38–42] with myofascial pain-dysfunction and craniomandibular disorder groups[42–45] has been questioned.[46,47] Curiously, no reference is made to recording vertical dimension in these studies.[38–45]

Thus, the concept of a unique physiologic rest position based on minimum masseter and associated muscle activity as discussed above is not well supported by the findings of the present study and related literature. Difficulties arise in its definition, recording, and measurement. Physiologic rest position is subject to variables of recording technique, EMG and IORS recording equipment, degree and method of muscle relaxation, mental state of the subject and variation between muscles, prior jaw motion, and even the subjectivity of the observer.[8,48]

While mandibular posture is continuously moving, 3 distinct recordable vertical ranges emerge from the dental literature: clinical rest position (1 to 4 mm), MERP to MERR (3.5 to 12 mm), and maximum bite force relation (5 to 22 mm),[51–58] with various degrees of overlap (Table 1). Clinical rest position is recorded as the mandible is relaxed immediately following phonation, swallowing, or tooth closure, or combinations thereof.[4–7,12,18,48,49] As the musculature is further relaxed from clinical rest position, the mandible assumes a more open range of positions that depends on the relaxation and recording methods used (Table 1).

The findings of this study show that with audio feedback minimum masseter EMG levels close to prerecorded baseline levels were achieved independent of vertical dimension and opening or closing sequence. This is in contrast to studies finding an MERP for masseter and associated muscles. These and inconsistent findings of other studies indicate that previous definitions of rest position as a unique postural relation at minimal contractual activity are inappropriate; the idea of overlapping ranges may be more realistic.

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Literature Abstracts

Analysis of 356 pterygomaxillary implants in edentulous arches for fixed prosthesis anchorage.

This follow-up study included all patients with Brånemark system implants (Nobel Biocare) in a private clinic. A total of 1,817 implants was placed in the maxillae of 189 patients. Of the implants, 356 were placed in pterygomaxillary sites; 16 different types of implant were used in this region, most of them 15 mm long. The cumulative survival rate of implants in the pterygomaxillary area was 88.2% after a mean functional period of 4.68 years. There were 41 failed implants at stage 2 surgery, and one implant was lost following loading. No obvious difference in survival was found between the different implant types. It was concluded that the survival rate of pterygomaxillary implants compares favorably with implants used in other areas of the maxilla. Pterygomaxillary implants provide posterior bone support without sinus augmentation or supplemental grafting.

Balshi TJ, Wolfinger GJ, Balshi SF. *Int J Oral Maxillofac Implants* 1999;14:398–406. **References:** 40. **Reprints:** Dr Thomas J. Balshi, Prosthodontic Intermedia, 467 Pennsylvania Avenue, # 201, Fort Washington, Pennsylvania 19034—*SP*

Comparison of patients' appreciation of 500 complete dentures and clinical assessment of quality.

Prosthodontic teaching assumes that clinical quality and patient appreciation of complete dentures are related. Some studies have corroborated this assumption while others have failed to do so. The aim of this study was to further investigate this inconclusive relationship in an extensive material of complete denture wearers. Denture quality was assessed by a prosthodontist. Patients graded their appreciation of the dentures on a 4-point scale. Multiple correspondence analysis was used for the association between patient and prosthodontist ratings. The results demonstrated close correspondence between dentist and patient appreciation of dentures when the dentures were rated as poor. However, there was little or no correspondence for better scores, ie, when the dentures were rated highly. It must be remembered that all of the patients in this study presented for replacement of their dentures. The authors emphasized that the findings may not be relevant to new complete dentures.

Fenlon MR, Sherriff M, Walter JD. *Eur J Prosthodont Restorative Dent* 1999;7:11–14. **References:** 13. **Reprints:** Dr Michael R. Fenlon, Department of Prosthodontic Dentistry, Floor 20, Guy's Dental Hospital, London SEI 9RT, UK—*AW*