Muscle Response during Treatment of Class II Division 1 Malocclusion with Forsus Fatigue Resistant Device

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Purpose: *To evaluate the muscle response in order to determine the mechanism of neuromuscular adaptations with Forsus Fatigue Resistant Device™ which has greater elasticity and flexibility; allows greater range of movement of mandible; is available in pre fabricated assembly of springs, tubes and rods and is a simple, effective and reliable corrective appliance that benefits not only growing patients but also malocclusions that previously required extractions, headgears and surgery.* ***Method:*** *Bilateral EMG activity from anterior temporalis and masseter muscles was monitored longitudinally on 10 young growing females with Class II Division 1 malocclusion to determine changes in postural, swallowing, and maximal voluntary clenching over an observation period of 6 months.* ***Results:*** *There was a significant decrease in the muscle activity at one month after Forsus Fatigue Resistant Device™ insertion during swallowing of saliva and maximal voluntary clenching which gradually returned to pre treatment levels at the end of six months.* ***Conclusion:*** *This study suggests that Forsus Fatigue Resistant Device™ should be given for at least six months to allow for adequate neuromuscular adaptations to occur for long term stability of the result.*

Keywords: *Mandibular advancement, Forsus, Electromyography, Children, Class II, malocclusion.*
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INTRODUCTION

Functional appliances used in the correction of Class II malocclusion modify the neuromuscular environment of the dentition and associated bones[1] and the ensuing skeletal alterations have been attributed to morphologic adaptations to an altered muscular tone and to a change in direction of traction exerted by the masticatory muscles.[2] However, the interaction between bone and muscle and the mechanism of neuromuscular adaptation to functional appliance therapy is complex and open to discussion. André sen and Haü pl[3] claimed that myostatic reflex leading to isometric contractions from the activities of the jaw-closing muscles is produced, which stimulates the protractor muscles and inhibits the retractor muscles of the mandible. Selmer- Olsen,[4] Umehara,[5] failed to observe active muscle contractions and claimed that the viscoelastic properties of the muscles and the stretching of soft tissues are decisive. Between the 2 extremes Witt[6] supported a combination of isometric muscle contractions and viscoelastic properties being responsible for the forces delivered. Concepts of Herren[7] (increased tonus), Schwartz[8] (long-lasting isometric biting), and Ahlgren[9] (passive elastic muscle tension) became important on testing the original hypothesis of André sen-Haü pl.[3] The hallmark of all these previous EMG studies was that they were based on a removable functional appliance that uses intermittent condylar displacement. Fixed functional appliances on the other hand are worn full-time, use continuous displacement and therefore can be expected to elicit a greater and more rapid neuromuscular response. Forsus Fatigue Resistant Device,™ being a flexible fixed functional appliances has more elasticity/flexibility and exerts a continuous and elastic force that allows greater freedom of movement of the mandible; patients can carry out the lateral movements with ease; can close in centric relation; repeatedly bite with the appliance voluntarily and during swallowing of saliva thereby activating greater occlusal contacts on biting and muscular force is distributed over a larger periodontal area which results in less inhibition of jaw elevator muscles by the periodontal mechanoreceptors thereby resulting in better mandible stabilization. Although response of masticatory muscles to removable functional appliances and Herbst appliance (a rigid fixed functional appliance) is

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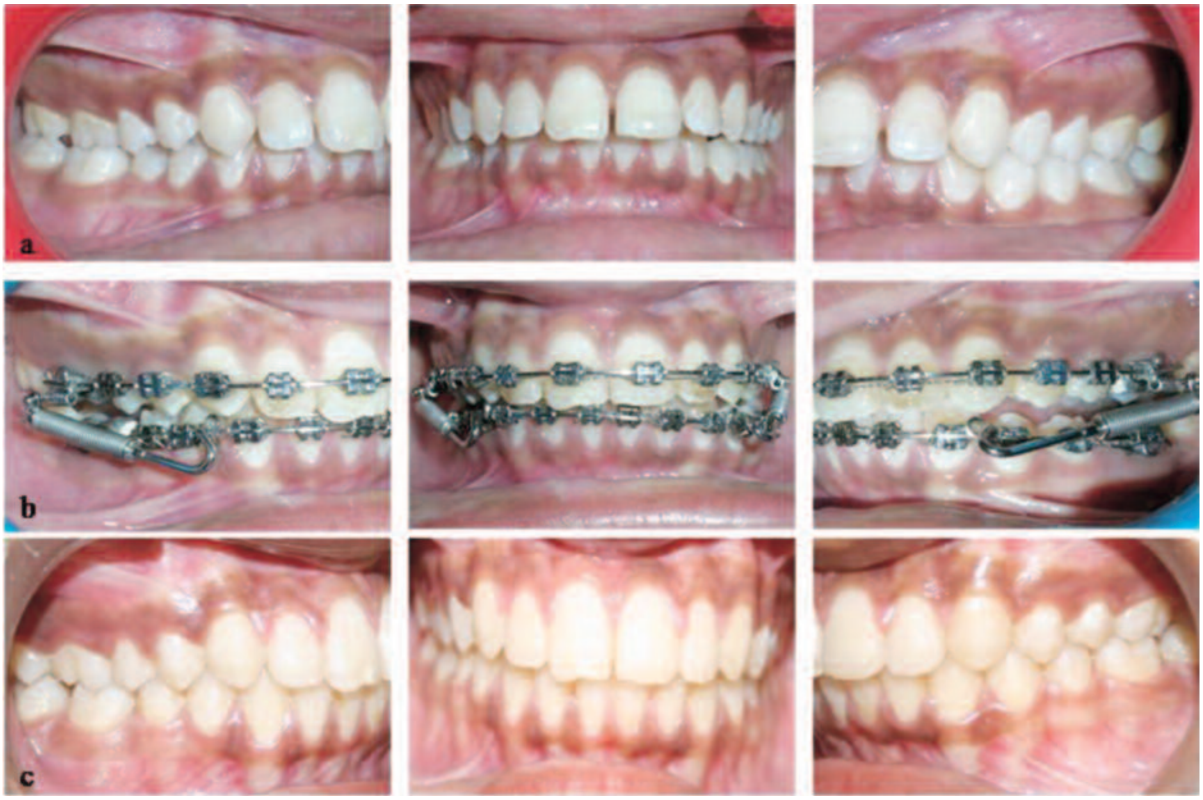

Figure 1. a) Intraoral Pre-treatment photograph of representative case; b) Intraoral mid-treatment photograph with Forsus Fatigue Resistant DeviceTM; c) Intraoral Post-treatment photograph of representative case.

available in literature, we could not find any study in published literature that has been conducted to see the muscle response with flexible fixed functional appliance. Thus aim of this study was to evaluate the muscle response to determine the mechanism of neuromuscular adaptations during treatment of Class II division 1 malocclusion with Forsus Fatigue Resistant Device.™

MATERIALS AND METHOD

This study was conducted on 10 young growing females in the age group of 10 - 14 years (mean age 12.5 years) having Class II division 1 malocclusion (Fig. 1a), average growth pattern, minimum crowding (<2 mm), a positive VTO (Visual Treatment Objective) and were free of subjective neuromuscular, auditory, or mandibular dysfunction symptoms. Class II division 1 malocclusion was diagnosed from the pretreatment clinical examination, dental casts and lateral cephalogram. The patients had full Class II molar and canine relationships (increased overjet, ANB, Wits and Convexity at point A). Other factors that contributed in the development of Class II division 1 malocclusion were decreased mandibular length (Co-Gn) and mandibular retrusion (Nperp-Pg).[10] Informed consent was taken from parent/guardian of these patients for being a part of this study. These patients underwent non extraction fixed orthodontic mechanotherapy with standard edgewise and the arches were aligned and levelled to 0.019" x 0.025" stainless steel wire, lingual crown torque of 10-15º was given in the lower anterior segment and the upper and lower arch wires were cinched back. Mandible was advanced to Class I molar relation with Forsus Fatigue Resistant Device™ (Fig. 1b) which was given for a period of 6 months following which it was removed and muscle activity was recorded longitudinally over a period of six months.

The procedure of recording the EMG was explained in detail to the patient to allay anxiety. The environment in which recordings were made was calm, quiet, and in a semi dark shielded room to eliminate outside electrical interferences. The patients sat in a comfortable upright position, with the head parallel to the ground, feet on the floor, and arms resting on their thighs. Postural position at rest was defined as its position when the subject was sitting motionless in the chair with maxillary and mandibular teeth a few millimetres apart and with no visible oral and facial activity such as tongue thrusting or licking of lips and they were instructed to relax and remain that way. The position of the electrodes was determined by palpation, and maximum voluntary contraction was performed to guarantee that the muscles were accurately located. Before placing the electrodes, the subjects were asked to wash their face with soap and water. The patients' skin was cleansed with alcohol to eliminate any grease or pollution residue and dried thoroughly and conductive paste was applied on to the surface electrodes before placing them. The electrode placement (Fig. 2)

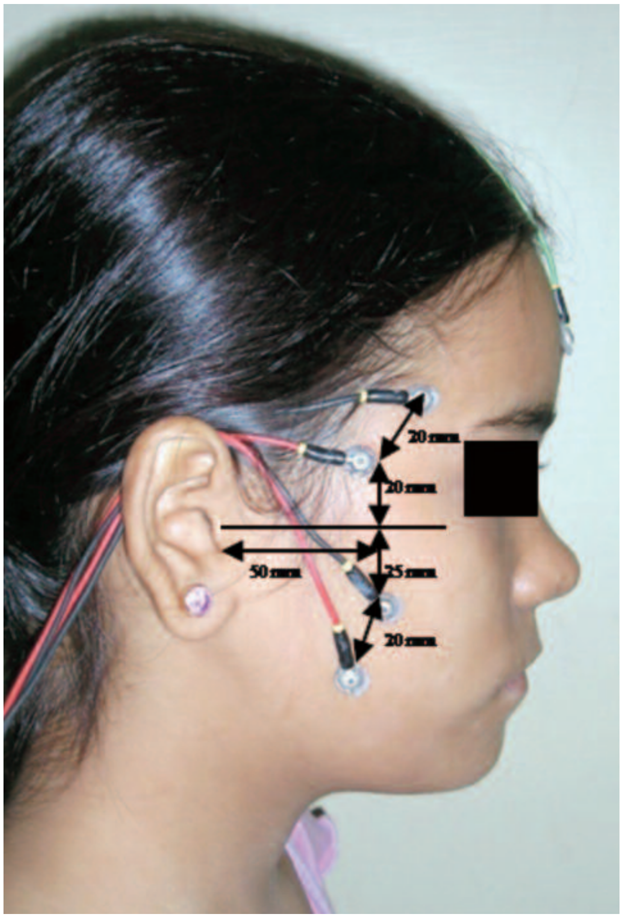

Figure 2. Electrode placement on anterior temporalis and masseter muscles.

was standardized according to the method advocated by Yuen *et al* [11] A 5-channel EMG, Medelec Synergy N-EP system (Oxford Instruments Medical, Inc.) were used with simultaneous acquisition, common grounding for all channels. Four channels recorded EMG activity from the anterior temporalis and masseter muscles. The remaining one channel which was used as reference electrode to reduce electromagnetic interferences and other acquisition noise was positioned over the forehead of the subject of the subject just above the glabella. Each patient underwent 5 EMG registration sessions (Fig. 3). The EMG activity was filtered for the range of 10 Hz (low cut filters) to 5 KHz (Hi cut filters); entrance of 10 GΩ in a differential mode, 12 bits of dynamic resolution, band of amplitude, –10 V to +10 V; and sample frequency by channel of 2 KHz. Myoelectric signals were captured by various active bipolar surface disk electrodes with 2 contacts with a distance of 20 mm apart, impedance upwards of 10 GΩ, and a common rejection value of 130 dB to 60 Hz. Length of the recording session of EMG for each activity was 5 seconds. To avoid muscle fatigue a relaxation period of 3 minutes was allowed between each functional activity and the next.

In order to evaluate the reproducibility of the EMG records, a section of the EMG signal, where the activity in all channels was steady and minimal over a 5-second period was measured twice on 3 different locations for each recording and the average of the first 3 different consecutive measurements of 1 function in 1 recording session was compared with the second measurement. For example, the average of the first 3 consecutive pre-treatment amplitude values of maximum voluntary clenching was compared with the average of the second 3 consecutive pre-treatment amplitude

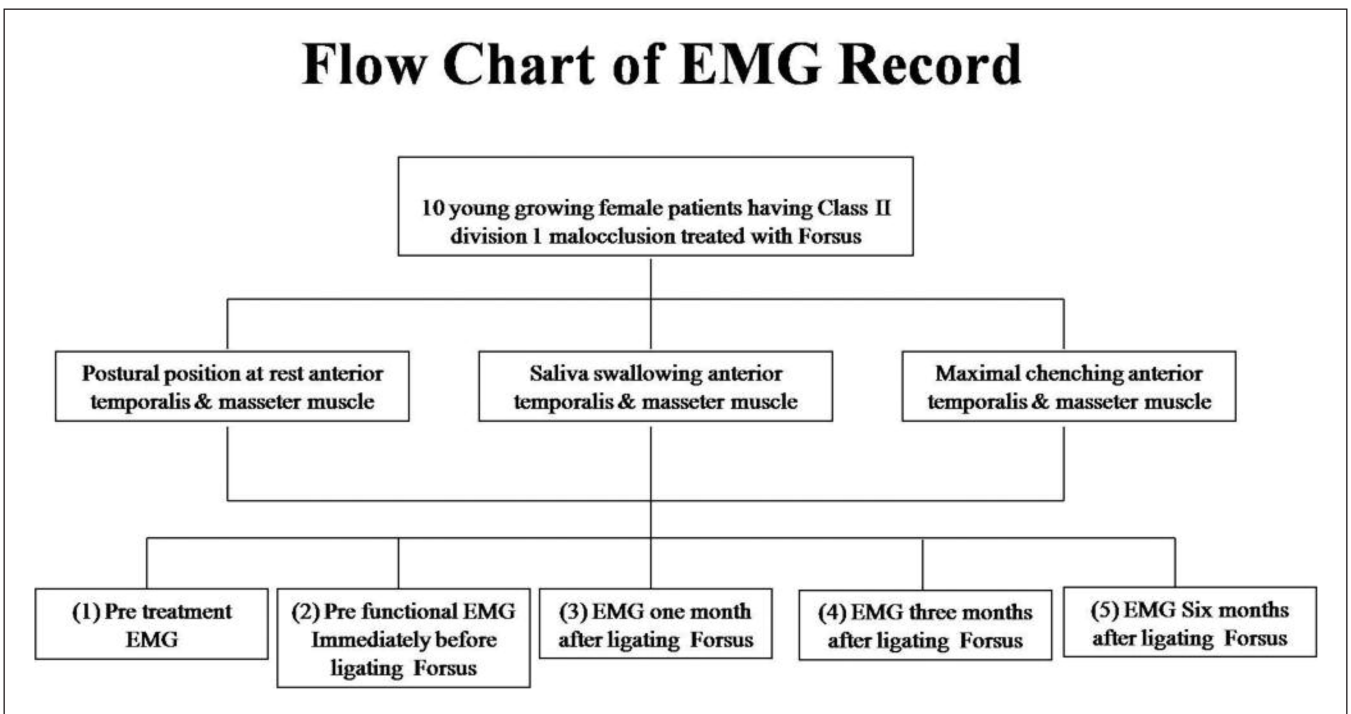

Figure 3. Flow chart of EMG record.

values of maximum voluntary clenching. Intraclass correlation coefficient values were calculated for each function at each session and were statistically significant, with values between 0.80 and 0.92. The same operator made all recordings. The EMG data were analyzed with SPSS for Windows software. Descriptive statistics including arithmetic mean and standard deviation were calculated. Friedman two-way nonparametric analysis of variance was employed to see the change in EMG activity over the six-month observation period. Multiple range tests were employed to determine the change in EMG activity between various recording sessions at different time intervals and to confirm the time interval in which significant change occurred.

RESULTS

When observing the EMG activity in patients treated with Forsus over an observation period of six months, there was no significant difference detected in the present study in postural position of the mandible (Table I), however there was significant decrease in muscle activity at one month during swallowing of saliva ($p< .05$) (Table II) and maximal voluntary clenching ($p< .05$ and $p< .01$) (Table III). The EMG values remained decreased for up to 1 month, gradually returning toward pre appliance levels near the end of the experimental period (6 months). The Forsus Fatigue Resistant Device™ used in our study was very effective in correcting the malocclusion (Fig. 1c) (Table IV).

DISCUSSION

Mode of action of functional appliance therapy has been linked to neuromuscular and skeletal adaptations to altered function in orofacial region. Modification of functional position of the mandible results in an immediate alteration of the neuromuscular activity of orofacial muscles.[12] Several investigations have been carried out to correlate the timing of the appearance and disappearance of altered functional patterns to the rate and extent of skeletal and dental adaptations.[13-15]

In this study we chose to record the EMG activity at pre treatment stage (1) as it was our baseline muscle activity, at pre functional stage (2) as after levelling there might be a possibility of change in the activity of the muscles due to disturbance in the occlusion, at one month (3) as neuromuscular changes might occur earlier than the morphological changes, at three months (4) because positional response of the mandible with the functional appliance is often noted at this time, at six months (5) as some children might present late response.

The scope of this study was not to compare untreated Class II division 1 malocclusion subjects with those treated with Forsus™, but to verify muscular alterations associated it. Thus, there was no control group of untreated Class II division 1 malocclusion subjects. Our control group was the subjects at pre treatment stage (1). In addition, EMG differences between subjects are more significant because of variables such as different cutaneous and subcutaneous tissue

Table I. Mean and S.D. values of the muscle activity in the postural position of the mandible over six month observation period

Appliance	Muscle	EMG Recordings (in μV)					Difference
		(1) Pre Treatment	(2) Pre Functional immediately before ligating Forsus™	(3) 1 month after ligating Forsus™	(4) 3 months after ligating Forsus™	(5) 6 months after ligating Forsus™	p
Forsus™ (n=10)	Anterior Temporalis	43.59 ±8.14	42.79 ±8.16	40.93 ±8.06	41.84 ±8.22	42.03 ±8.09	NS
	Masseter	41.17 ±8.12	41.62 ±8.3	40.83 ±8.21	41.8 ±8.11	42.02 ±8.23	NS

(NS) = Not Significant

TABLE II. Mean and S.D. values of the muscle activity during swallowing of saliva over six month observation period

Appliance	Muscle	EMG Recordings (in μV)					Difference
		(1) Pre Treatment	(2) Pre Functional immediately before ligating Forsus™	(3) 1 month after ligating Forsus™	(4) 3 months after ligating Forsus™	(5) 6 months after ligating Forsus™	p
Forsus™ (n=10)	Anterior Temporalis	119.02 ±19.02	117.02 ±18.51	91.21 ±12.09	101.04 ±16.07	105.31 ±18.37	1 Vs 3* 2 Vs 3* 3 Vs 5* 3 Vs 4*
	Masseter	105.95 ±11.46	103.12 ±11.22	85.58 ±11.99	94.74 ±13.72	97.22 ±17.51	1 Vs 3* 2 Vs 3* 3 Vs 5* 3 Vs 4*

* =p < 0.05

thickness, age, sex, facial characteristics, and other biologic characteristics. We believe that using the subjects as controls avoids this variable in assessing the muscular alterations with the treatment and we can attribute that the difference to altered occlusion. Other studies also evaluated the EMG activity of the masticatory muscles before and after orthodontic treatment with the subjects as the control group.[16,17]

Muscle activity over six month observation period

Our results are in accordance with the findings of previous studies[13, 18, 19] which reported decrease in the muscle activity of masticatory muscles in children undergoing treatment. The findings of our study also agree with the studies done on Herbst appliance[20,21,22] where the muscle activity was found to decrease. Our results do not support the findings of Ahlgren[9]

TABLE III. Mean and S.D. values of the muscle activity during maximal voluntary clenching over six month observation period

Appliance	Muscle	EMG Recordings (in μV)					Difference
		(1) Pre Treatment	(2) Pre Functional immediately before ligating Forsus™	(3) 1 month after ligating Forsus™	(4) 3 months after ligating Forsus™	(5) 6 months after ligating Forsus™	p
Forsus™ (n=10)	Anterior Temporalis	532.57 ±108.04	528.75 ±106.59	421.39 ±88.56	472.82 ±95.65	497.95 ±106.25	1 Vs 3** 2 Vs 3** 3 Vs 5** 3 Vs 4** 1 Vs 4* 2 Vs 4* 4 Vs 5*
	Masseter	490.36 ±100.35	483.17 ±100.39	394.11 ±89.11	447.34 ±92.65	463.81 ±104.8	1 Vs 3** 2 Vs 3** 3 Vs 5** 3 Vs 4** 1 Vs 4* 2 Vs 4* 4 Vs 5*

* =p < 0.05; **= p<0.01

Table IV. Pre and post-treatment cephalometric changes observed with Forsus™

	Variable	Mean±S.D	
		Pre-treatment	Post-treatment
Skeletal	FMA	23±2.05^0	24±1.97^0
	SNA	80.3±2.32^0	79.76±2.2^0
	SNB	74.28±1.76^0	77.56±1.5^0
	ANB	4.5±1.5^0	2.18±0.91^0
	Nperp-A	1.53±1.03 mm	1.42±1.21 mm
	Nperp-Pg	-10.75±4.32 mm	-6.82±5.13 mm
	Co-Gn	78.86±5.3 mm	82.91±3.15 mm
	Wits (AO-BO)	3.2± 1.6 mm	1.08±0.38 mm
	Convexity at point A (relative to N-Pg)	3.9 ± 2.69 mm	1.16±2.24 mm
Dental	IMPA	95.43±4.02^0	99.2±4.39^0
	U1-SN	106.82±4.12^0	106.13±3.24^0
	Overjet	4.5±2.5 mm	0.82±0.26 mm
Soft tissue	Nasolabial angle	111.32±7.3^0	109.4±9.12^0
	U lip-S line	2.24±1.42 mm	1.12±1.61 mm
	L lip-S line	1.74±2.1 mm	2.8±2.5 mm

and Aggarwal *et al* [16] who reported increase in postural & swallowing EMG activity following treatment with an activator and twin block respectively. Swallowing of saliva on command is a very commonly used experimental procedure to evaluate muscle function, often referred to as "empty swallowing." During natural "reflex" swallowing, the effort is less. A limitation of the procedure is that it depends largely on how much effort is exerted during the exercise. Alternatively the increased muscle activity seen in these studies done with removable functional appliances can be explained, as result of greater flow of saliva caused by the introduction of an insoluble material in the mouth. Also with removable functional appliances, there are chances of exceeding the vertical dimension which might also lead to increased muscle activity observed during swallowing of saliva seen in these studies. Alternatively it could be a result of better mandible stabilization and the increase of occlusal contact area with the removable functional appliance, thereby causing the muscular force to be distributed over a higher periodontal area and diminishing jaw elevator muscle inhibition by periodontal mechanoreceptors.

In an animal study[21] initial placement of the Herbst appliance to induce marked mandibular protrusion was associated with a statistically significant decrease in EMG activity which persisted for approximately six weeks. From the changing pattern of EMG recordings obtained in our study (Fig. 4), it was obvious that the lowest EMG activity during treatment also occurred within the first month. During the third to the sixth month of treatment period, when most of the skeletal adaptations occur and occlusal contacts are achieved, there was a steady increase of EMG activity. During the final six months of treatment, the EMG activity seemingly continued to increase towards the pre treatment level which indicates that there was no obvious difficulty in adapting to a new position of the mandible achieved after six months of active treatment with Forsus Fatigue Resistant Device™. These results are in accordance with the findings of Pancherz and Anehus- Pancherz[22] who reported that the immediate response to treatment was a strong reduction in masseter and temporalis activity during clenching and a gradual increase in muscle activity occurred from 1 month onward until the end of 6 months. Biting on appliance has also shown a reduced masseter and anterior temporal muscle activity.[23,24,25] In normal occlusion also, when the mandible was protracted, the anterior temporal muscle activity has also been found to be reduced.[15] Myofunctional appliances have been shown to decrease orofacial muscle activity during oral function.[26] The results of our study support a concept that no increases are induced in the EMG activity while using functional appliances.[9,13,18,21]

In our view muscle activity decreases following insertion of Forsus Fatigue Resistant Device™, as it results in occlusal instability due to changed tooth position and inter maxillary relations brought about by active protrusion with the appliance. A correlation exists between impaired EMG activity from the masticatory muscles and cusp-to-cusp occlusion and a stable occlusion is a prerequisite for maximal muscle activity during biting.[27-29] When clenching in the intercuspal position is directed anteriorly, as with Forsus Fatigue Resistant Device™ during first month, muscle activity decreases dramatically with lessening numbers of posterior teeth in contact and drops significantly when only the incisors are in contact. It has been found that during biting in the maximal occlusion a vast number of mechanoreceptors, located in the periodontal ligaments of the posterior teeth are activated. This number is probably decreased in the incisor edge to edge position, whereby antagonistic tooth contacts are restricted to a few anteriorly located teeth thus leaving the posterior teeth out of occlusion. This alters the sensory input to receptors in masticatory muscles thereby altering the position of muscle balance, so that it becomes painful for the patient to retract the mandible[12] and results in immediate change in the neuromuscular response, thus interfering with the physiologic function of the stomatognathic system, masticatory performance is reduced, the lateral mandibular movement capacity is decreased, muscle tenderness is increased and this continues during the first few months of treatment. The muscles must re-establish their balance if the teeth are to remain in their new position achieved as a result of treatment with fixed functional appliance.

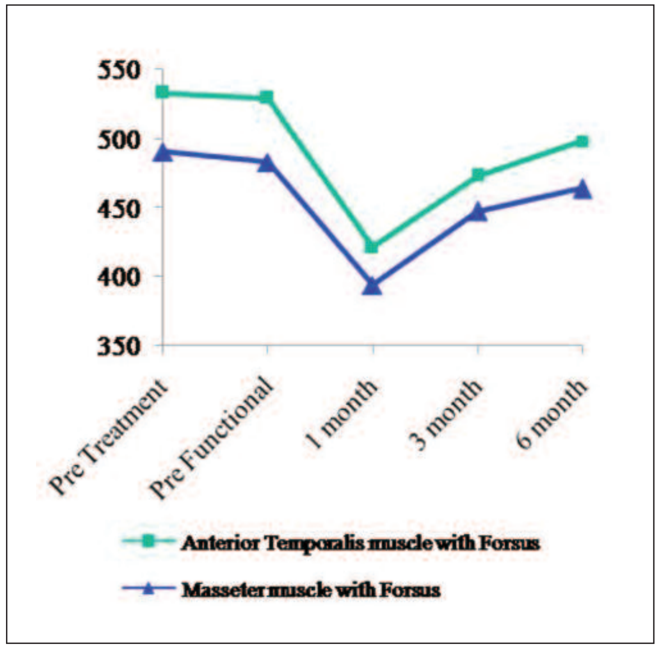

Figure 4. Changes in EMG activity during maximal voluntary clenching over six month observation period.

A stimulus is sent to CNS and a very complex interaction takes place to determine the appropriate response. The cortex with influence from thalamus, central pattern generator (i.e. pool of neurons that controls muscle activities), limbic system, reticular formation and hypothalamus determines the action that will be taken in terms of direction and intensity. For central pattern generator to be most efficient, it receives constant sensory input from tongue, lips, teeth, periodontal ligament, masticatory muscles and temporomandibular joint to determine the most appropriate path of closure. Once this is established, it is learned and repeated and this learned pattern is called *muscle engram*. It is rare for such a response to be observed with functional appliances that are not worn full time. Forsus Fatigue Resistant Device™ keeps the mandible in a protrusive posture constantly and does not permit shortening of the elevators as a result of which the muscle fibers develop a higher tension. This uninterrupted stretch on the muscle spindles increases the frequency of reflex contractions in the masticatory muscle[11] that involves a change in γ (gamma) efferent output via the reticular formation and the cerebellum rather than purely reflex stimulation of muscle spindles.

After a few months when some occlusal contacts are re-established, temporal and masseter muscle activity starts gradually increasing to pre-treatment levels, as when skeletal adaptations occur the need for compensatory muscle function is reduced. The 3-month registration appears crucial for analyzing the neuromuscular changes occurring with treatment, indicating a strong possibility that sagittal repositioning of a retruded mandible in Class II division 1 cases takes place approximately within 3 months of initiating the Forsus Fatigue Resistant Device™ treatment. By the end of 6 months with progress of treatment, as a result of better mandible stabilization and an increase of occlusal contact area, the occlusal load of clenching was distributed over a larger periodontal area, and a significant increase in clenching activity occurred.

Alternatively this decrease in EMG activity can also be explained by the fact that when the muscle is lengthened and isometrically contracted, the EMG activity falls, although the tension is greater. This is in accordance with the active muscle activity in the isometric length-tension curve.[30] This can also be interpreted as an effect of reciprocal innervation[31] the temporalis muscle being an antagonistic muscle to a protrusive movement of the mandible. Alternatively, it can be accounted for because of the relative inexperience with the wear of the fixed functional appliance during the first few months and apprehension of soft tissue damage and breakage.

From the significant decrease in EMG activity of masseter and anterior temporal muscles seen in our study, we support the view that passive tension associated with viscoelastic properties of soft tissues rather than active contraction of the jaw closing muscles play an important role in mechanism of neuromuscular adaptation with Forsus Fatigue Resistant Device™, because of a much longer duration of forces from passive tension.[19, 21] It is proposed that the insertion of Forsus Fatigue Resistant Device™ induces motor reprogramming and result in postural adoption which in turn leads to a growth response.

The muscle activity, in this study was examined over a period of six months of the treatment with Forsus Fatigue Resistant Device™ which had imposed alterations in the neuromuscular response in the treated subjects, and a complete neuromuscular adaptation had occurred as seen by the lack of statistically significant differences in EMG values at the start of the treatment and at the end of six months (1 *versus* 5). These findings of our study suggest that Forsus Fatigue Resistant Device™ should be given for at least six months to allow for adequate neuromuscular adaptations to occur for long term stability of the result.

It seems that quantitative EMG of the masticatory muscles can be used as an informative tool in the evaluation of treatment results and can be added to the conventional dentofacial measurements.

CONCLUSIONS

A definite response of anterior temporalis and masseter muscles was observed and there was adequate neuromuscular adaptation following insertion of Forsus Fatigue Resistant Device™ at the end of six months.

There was a significant decrease in the muscle activity at one month after Forsus Fatigue Resistant Device™ insertion during swallowing of saliva and maximal voluntary clenching which gradually returned to pre treatment levels at the end of six months which suggests that this appliance should be given for at least six months to allow for adequate neuromuscular adaptations to occur for long term stability of the result.

Since EMG activity in the muscles investigated in the present study is decreased significantly, our data is consistent with the concept which assigns a major role to the viscoelastic elements of muscle and increased lip strength as the source of stimulus for bone remodelling associated with the action of this appliance.

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