Ph.D. Thesis

Influences of the activator and spring active appliance on masticatory muscle activity

咀嚼筋活動に対する
アクチベータと spring active appliance （SAA）
の影響

Hideki Tabe, D.D.S.

Department of Orthodontics
and
Craniofacial Developmental Biology
Hiroshima University
Graduate School of Biomedical Sciences

Hiroshima, Japan

2003

Supervisor

Prof. Dr. Kazuo Tanne, D.D.S., Ph. D.

Professor
Department of Orthodontics
and
Craniofacial Developmental Biology
Hiroshima University
Graduate School of Biomedical Sciences
Hiroshima, Japan

Dedication

This thesis is dedicated to my father and mother whose understanding and inspiration made possible to complete my education

Contents

1. Introduction 1

1.1 Preface 1
1.2 Review of the literature 1
1.3 Purpose of the present study 5

2. Subjects and methods 7

2.1 Subjects 7
2.2 Experimental appliances 7
2.3 EMG recording 10
2.4 Experimental procedures 11
2.4.1 Long time EMG recording during daytime and sleep 11
2.4.2 Short time EMG recording during voluntary biting 11
2.4.3 Measurement of mandibular displacement with the appliances in use 12
2.5 Data analysis 12

3. Results 15

3.1 Muscle activity with and without the appliances during daytime 15
3.2 Muscle activity with and without the appliances during sleep 15
3.3 Muscle activity with and without the appliances during voluntary biting under unconscious condition 17
3.4 T/M ratio 20
3.5 Mandibular displacement with the activator and SAA 21

4. Discussion 22

4.1 Methodology in the present study 22
4.2 Changes in integrated muscle activity with functional appliances under unconscious condition during daytime and sleep 25
4.3 Changes in integrated muscle activity with functional appliances under conscious condition during biting 28
4.4 The activator and SAA 30
4.5 Clinical implication 31

5. Conclusions 34

6. Acknowledgements 36

7. References 37

1. Introduction

1.1 Preface

Functional appliances for Class II patients are unique among orthodontic appliances in terms of producing morphologic alterations in the dentoalveolar structure indirectly through stimulus to the masticatory system. The activator is a representative of these appliances and is used mostly during sleep. In previous studies, there has been much controversy about the action mechanisms of activator and other functional appliances, particularly about whether functional appliances stimulate orofacial muscle activity or not. Currently, it is hypothesized that the resultant passive tension plays an important role in the action mechanisms of activator rather than active contraction of the jaw closing muscle.

Meanwhile, it is well known that craniofacial growth is highly related with the activity of orofacial muscles attached to the bones. Given the consideration, one question may be raised, *i.e.* how the muscle activity is induced through functional appliances ?

It is thus of a great significance to elucidate the nature of masticatory muscle activity with use of functional appliances in such different situations as during sleep, daytime at rest, and voluntary biting by means of electromyogram (EMG).

1.2 Review of the literature

Functional appliance, which is considered to stimulate mandibular growth through the effect on condyle or glenoid fossa remodeling (McNamara 1973; McNamara and Carlson 1979; McNamara et al. 1982; Birkebaek et al. 1984; Woodside et al. 1987; Ruf et al. 2001) in growing patients with retrognathia, is widely used with various designs in daily orthodontic practice (Graber and Neumann 1984; Iscan et al. 1992; Yamin-Lacouture et al. 1997; Stellzig et al. 1999; Read and Orth 2001). Among them, activator, introduced by Andresen and Häupl (1936), is of a great significance and has been used successfully up to present in clinical orthodontics. Clinical and cephalometric studies (Meach 1966; Freunthaller 1967; Birkebaek et al. 1984; Jakobsson and Paulin 1990; Suto et al. 1998; Kaku et al. 2000; Yoshida et al. 2001) demonstrated that activator is effective for producing dentofacial alternations to correct malocclusions, and has different aspects from fixed appliances (Carels and van der Linden 1987; Bishara and Ziaja 1989).

Effects of activator on masticatory muscle activity have been reported extensively in the literatures. For the mode of action of activator, many findings and hypotheses have also been described in the literature. Andresen and Häupl (1936) indicated that, with the use of activator, the protraction muscles of the mandible such as the masseter muscle are stimulated, whereas retraction muscles such as posterior portion of the temporalis are inhibited, and suggested that the action mechanism is due to activation of the masticatory muscles. On the contrary, Selmer-Olsen (1937) reported that significant activity of the jaw closing muscles could not be expected by the use of activator during sleep. Umehara (1941) noted that functional vibration derived from voluntary biting action was not induced by the nocturnal use of activator. Furthermore, Eschler (1952) demonstrated that wearing such an activator increased the activities of the temporal, masseter, and orbicularis oris muscles.

Since then, several studies have been conducted to investigate the effects of the functional appliances and to confirm the fact that functional appliances activate orofacial muscles (Herren 1959; Grossmann et al. 1961; Jakobsson 1967; Harvold and Vargervik 1971; Woodside et al. 1973; McNamara and Carson 1979; Freeland

1979; Pancherz and Anehus-Pancherz 1982; Carels and van Steenberghe 1986; Sessel et al. 1990; Yuen et al. 1990; Ingervall and Thüer 1991; Miyakawa et al. 1998; Tallgren et al. 1998; Hiyama et al. 2000). According to the results about Herbst appliance, Pancherz and Anehus-Pancherz (1980) demonstrated that the temporal and masseter muscles showed an increase in the activity during maximal biting and chewing of peanuts at the end of treatment as compared to the beginning without the appliance. This increased activity was more apparent in the masseter muscle than in the temporal muscle. During the use of the Herbst appliance, meanwhile, the activity of the temporal and masseter muscles during maximal biting and chewing was markedly reduced. Ingervall and Bitsanis (1986) reported that the bite force measured at the incisors increased during treatment. The muscle activity in the rest position with activator was low and the same as compared to the activity without activator. Thus, the muscle activity was not increased by the use of activator. The activity of the posterior portion of the temporal muscle in the rest position was comparatively high at the start of treatment but decreased during post-treatment observation, and such change may be due to an adaptation to a new mandibular position. Sessel et al. (1990) investigated muscle activity in monkeys with and without functional appliances. They described that the insertion of functional appliances to induce mandibular protrusion was associated with significant reduction of postural EMG activity of the superior and inferior heads of the lateral pterygoid muscles, and superficial portion of the masseter. Yamin-Lacouture et al. (1997) assessed the muscle activity with Herbst, Frankel and Clark functional appliances. They showed a statistically significant decrease in the activity of masseter and digastric muscles, and superior and inferior heads of the lateral pterygoid muscle with functional appliances. Uner et al. (1999) found a significant increase in masseter and anterior temporal muscle activities in the rest position with activator at the beginning of treatment.

Activities of both muscles with the activator in use decreased in the rest position at the end of treatment when compared to the beginning. No changes were found between the activities of masseter and temporal muscles recorded at the beginning and end of the investigation without the activator.

With relation to a difference in muscle activity between daytime and sleep, Tangel et al. (1992) demonstrated a significant decrease in the tonic activity of the masseter muscle during non-rapid-eye-movement (non-REM) sleep. This indicates that changes observed in masticatory muscle activity could be different between daytime and sleep. Previous reports demonstrated that there was no increase in the postural EMG activity while wearing functional appliances during sleep (Ahlgren 1960; Noro 1991; Noro et al. 1994; Hiyama et al. 2002). Therefore, it is proposed that a functional appliance should be used during daytime (Ahlgren 1960, 1978; Thilander and Filipsson 1966; Miralles et al. 1988; Noro 1991; Suto et al. 1998; Hiyama et al. 2002). Ahlgren (1960, 1970, 1978) found no increase in muscle activity in response to the use of activator during sleep, whereas an increased postural activity was detected in the masseter and suprahyoid muscles but not in the anterior and posterior temporal muscles during the daytime use. About daytime use of activator, he produced evidence lending support to the opinion of Andresen and Häupl (1936) that the action mechanism is due to activation of the masticatory muscles, but it was not applied during sleep. Thilander and Filipsson (1966) showed low activities of the masseter, posterior temporal, and suprahyoid muscles with activator in use "at rest", but these muscles with activator were intense "in function". Miralles et at. (1988) found a significant increase in muscle activity with activator in use during saliva swallowing, indicating an effectiveness of the diurnal use.

Meanwhile, SAA which has been introduced by Sander et al. (Sander and Wichelhaus 1989; Wichelhaus and Sander 1989; Sander and Weinreich 1990;

Sander 1991), has unique architecture and mechanics among functional removable appliances. In this appliance, the upper and lower acrylic bite plates with labial arches are consolidated by wire springs on the lingual sides. Effects of the appliance are almost comparable to the activator in terms of the correction of skeletal relationship. The appliance thus has been mostly used for the treatment of dental and skeletal open bites with small and/or distally-located mandible. The mechanisms of this appliance are to exert continuous tension in the neuromuscular system supporting the mandible, to inhibit vertical growth of the maxillomandibular skeleton, and to produce forward autorotation of the mandible, leading to the correction of open bite. In previous studies, the nature of morphologic and functional changes produced by such appliances has already been elucidated (Kuster and Ingervall 1992; Imoto et al. 1997; Akkaya et al. 2000).

In most of these studies, however, masticatory muscle activity was measured only for a limited short period before and after treatment. In order to elucidate the changes in the muscle activity during the use of functional appliances, therefore, it is of a significance to elucidate the nature of muscle activity for a longer period during daytime and sleep.

Furthermore, in orthodontic clinic, we sometimes instruct the patients to bite the appliance voluntarily during the daily use, but there has been only a limited number of studies for the effects of such application of activator on facial skeletal patterns or muscle activity (Miyakawa et al. 1998; Suto et al. 1998).

1.3 Purpose of the present study

The purpose of the present study was to evaluate the influences of activator and SAA on masticatory muscle activity, by means of recording EMG and mandibular movement. The present study consists of the following steps.

1. Long time EMG recording during daytime and sleep

2. Short time EMG recording during voluntary biting

3. Measurement of mandibular displacement with the appliances in use

2. Subjects and methods

2.1 Subjects

Subjects in the present study were 12 healthy adult males (mean age: 26.6 years) selected from the volunteers in the Faculty of Dentistry, Hiroshima University (Table 1). They had almost normal skeletal relations and nearly complete dentition without any serious malocclusions and temporomandibular joint disorders. Informed consents were obtained from all the subjects prior to the experiments after explaining the aim and design.

2.2 Experimental appliances

In the present study, three appliances, FKOh, SAAo, and SAAa, were used for each subject. FKOh is an activator referred to a design according to Ahlgren (1970). The construction bite was taken at the edge to edge occlusion with 3mm forward displacement of the mandible and vertical distance of 8 mm at the incisors (Fig. 1). SAAo had the same construction bite as FKOh (Fig. 2). For the SAAa, the construction bite at the molar part was activated twice as much as SAAo (Fig. 2).

Table 1: Summary of subjects in the present study (12 healthy adult males)

subjects	age (year)	overjet (mm)	overbite (mm)	molar relationship right	molar relationship left	ANB	mand. pl. A.
A	26	3.5	2.5	I	I	5.3	115.0
B	32	4.4	3.5	I	I	4.0	106.0
C	25	3.5	3.2	I	I	3.4	134.8
D	27	6.5	3.9	II	I	2.9	106.8
E	27	2.5	2.6	I	I	−0.5	112.3
F	24	3.8	2.5	I	I	2.0	129.2
G	25	4.8	3.4	I	I	7.2	125.8
H	26	1.6	1.1	I	I	0.7	133.5
I	26	4.8	3.9	I	I	5.2	120.5
J	26	3.2	2.0	II	II	6.0	112.7
K	25	2.2	1.8	I	I	0.2	123.0
L	30	4.7	4.8	I	I	2.1	115.9
average	26.6	3.8	2.9			3.2	119.6
S.D.	2.3	1.4	1.0			2.4	9.8

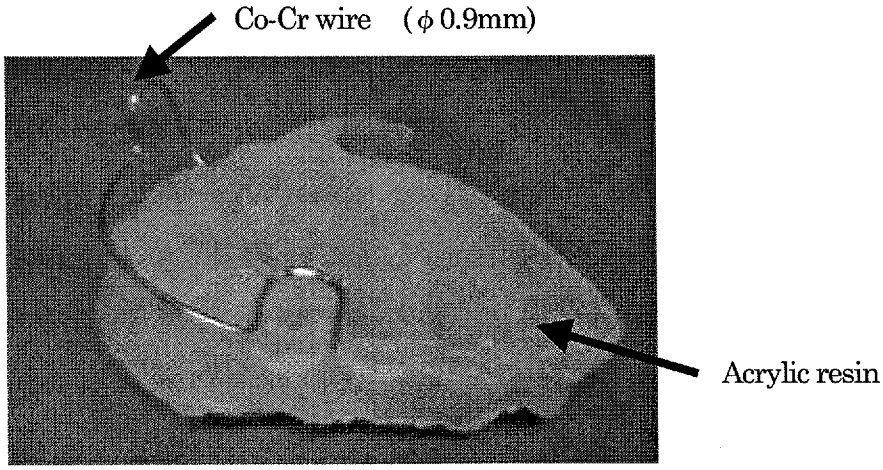


Figure 1. Activator (FKOh)

FKOh is an activator. The construction bite was taken at the edge to edge occlusion with 3mm forward displacement of the mandible and vertical distance of 8 mm at the incisors.

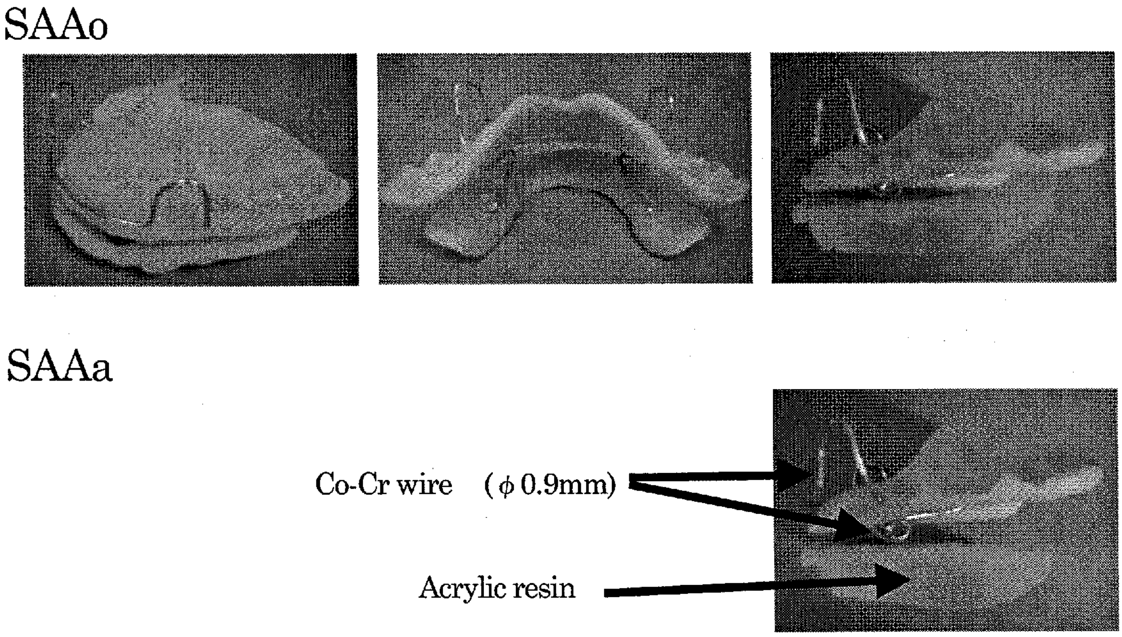
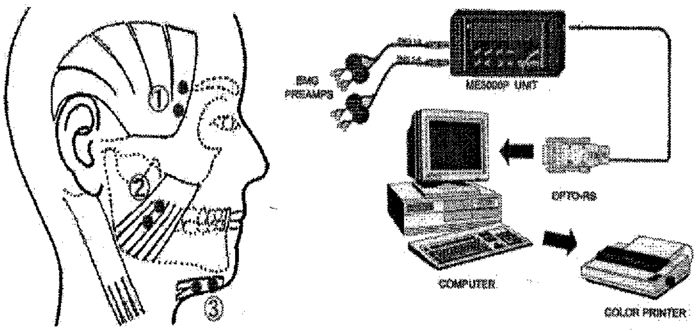


Figure 2. Spring active appliance (SAA), SAAo (upper) and SAAa (lower)

SAAo had the same construction bite as FKOh. For the SAAa, the construction bite at the molar part was activated twice as much as SAAo.

2.3 EMG recording

A digital EMG recording device (Muscle Tester ME3000P, Mega Electronics Ltd., Kuopio, Finland) and bi-polar silver silver-chloride electrodes (Blue sensor, type-N-00-S, Medicotest A/S, Ølstykke, Denmark) were used to record the EMG from the right anterior temporal (Temp), superficial portion of the right masseter (Mass), and anterior belly of the right digastric muscles (Dig). The electrodes were placed carefully according to our previous studies (Ueda et al. 1998; Saifuddin et al. 2001), as shown in Fig. 3. EMG data were recorded with a sampling frequency of 1 kHz. The means of rectified EMG data for every 0.1 second were stored into the recording device.



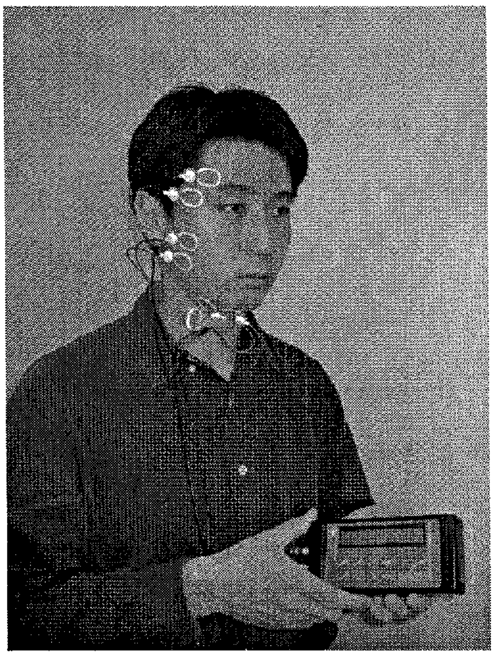
Placement of EMG surface electrodes

Right side

① anterior temporal muscle (Temp)

② superficial portion of masseter muscle (Mass)

③ anterior belly of digastric muscle (Dig)



ME3000P and electrodes

Figure 3. Placement of EMG surface electrodes

The electrodes were placed in the direction of the muscle fibers by palpation.

2.4 Experimental procedures

2.4.1 Long time EMG recording during daytime and sleep

In this experiment, three sessions were performed with and without the use of FKOh and SAAo on three different days with an interval of one week. In order to record muscle activity at rest, each subject was allowed to watch a video or TV sitting on an office chair in a small room. The diurnal recording was carried out for consecutive 220 minutes. During the measurement, they were requested to refrain from speaking and moving the head. After the diurnal recording, the subjects were dismissed to go back home with the electrodes in position and then the nocturnal EMG recording was performed for 220 minutes again in their bed at the usual sleep posture. The data for 30 minutes were excluded because of unstable status. The analysis was executed for the stable 190 minutes during daytime and sleep.

2.4.2 Short time EMG recording during voluntary biting

In this experiment, four sessions were performed. Each subject was requested to sit on an office chair in the upright position without head support. All the subjects were requested to bite voluntarily as to be able to go on all day long with their teeth in the intercuspal position, and with FKOh, SAAo, and SAAa between their teeth on the same day. In order to investigate the changes in muscle activity when biting the appliances, the activity of masseter, temporal and digastric muscles was recorded for each subject with and without the appliances (four sessions) for 12 minutes in each session. Each session was analyzed for the stable 9.5 minutes, which was converted to 190 minutes for the comparison with the long time data.

2.4.3 Measurement of mandibular displacement with the appliances in use

Mandibular displacements with the appliances in use were recorded by use of an optoelectronic jaw-tracking system (Gnathohexagraph system Ver. 1.31, Ono Sokki Ltd., Yokohama, Japan)(Fig. 4). This device makes it available to record various phenomena related to the stomatognathic function with six degrees of freedom and an accuracy of $\pm 150\ \mu m$ (Tokiwa and Kuwahara 1998). It consists of a head frame and facebow with a total of six light emitting diodes (LEDs). The face bow was so light (weight: 12g) enough to record even a very little displacement of the mandible at rest. Two CCD cameras are located in front of subject and the 3-D position of the LEDs is determined by use of angular and linear parallaxes between the two cameras (Fig. 4).

We recorded the displacement of two reference tracking points corresponding to the lower central incisor and right first molar by using a pointer with two light-emitting diodes. In order to elucidate the influences of FKOh and SAAo on mandibular movement, the maximum displacement was analyzed in each direction (coronal, horizontal, and midsagittal planes, which correspond to the Y-Z, X-Y, and Z-X planes) while using the appliances for 100 seconds (Fig. 5).

2.5 Data analysis

After recording, the data of EMG activities were moved to a personal computer. Data analysis was performed with an accessory software (Muscle Tester ME3000P Software v.1.4-program, Mega Electronics Ltd., Kuopio, Finland), and the integrated EMG values ($\mu V \cdot sec$) were worked out. Furthermore, T/M ratio as the proportion of the temporal and masseter muscle activities was calculated for each session.

In the present study, paired t-test was performed to examine the difference in muscle activity with and without the use of different functional appliances in the same condition, or with same appliance in different situations between two groups, and the difference in mandibular displacement with FKOh and SAAo.

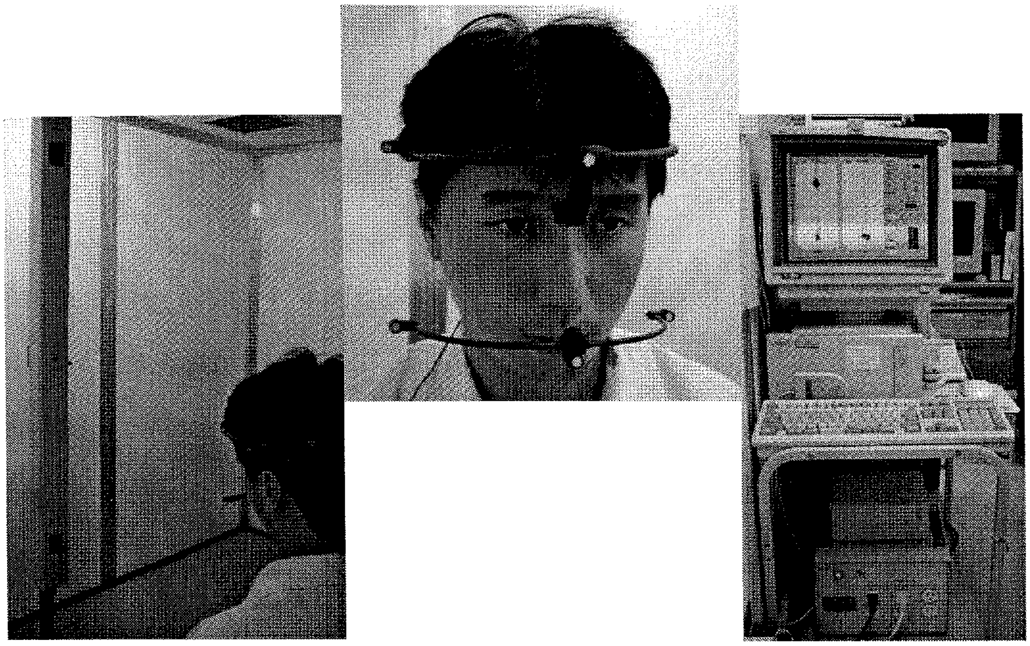
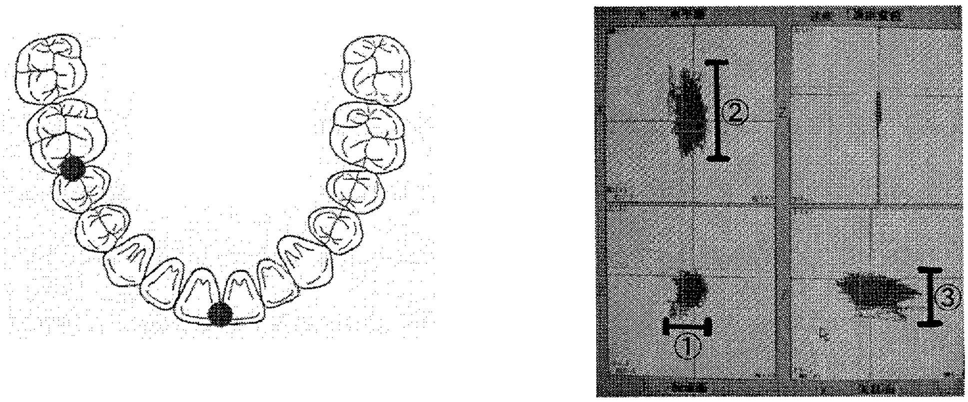


Figure 4. An optoelectronic jaw-tracking system (Gnathohexagraph)

Mandibular movements with the appliances in use were recorded by use of Gnathohexagraph.



Movements of two reference tracking points corresponding to the lower central incisor and right first molar were recorded.

The maximum displacement was analyzed in each direction (the coronal, horizontal, and midsagittal planes, which correspond to the ①Y-Z, ②X-Y, and ③Z-X planes).

Figure 5. Measurement of mandibular displacement

3. Results

3.1 Muscle activity with and without the appliances during daytime

The muscle activity with and without the appliances during daytime is compared, as shown in Fig. 6. Muscle activity with the FKOh tended to be more predominant than that with the SAAo for all the muscles. Muscle activity also tended to increase in the digastric muscle and to decrease in the temporal muscle with the appliances, whereas the changes were slightest in the masseter muscle.

The muscle activity induced by FKOh became significantly prominent in the digastric muscle ($p<0.05$), and SAAo also enhanced the digastric muscle activity. Temporal muscle activity with use of SAAo was significantly decreased. Meanwhile, no significant changes in masseter muscle activity were induced by the appliances in use.

3.2 Muscle activity with and without the appliances during sleep

Fig. 7 shows the integrated muscle activity during sleep. The activity of all the muscles during sleep was less than that during daytime in all the situations.

The activity of temporal and masseter muscles was significantly less with the appliance in use than without ($p<0.01$). In contrast, the digastric muscle activity tends to be greater with the appliances, different from the elevator muscles. No substantial differences were found in the activity of three muscles with two appliances.

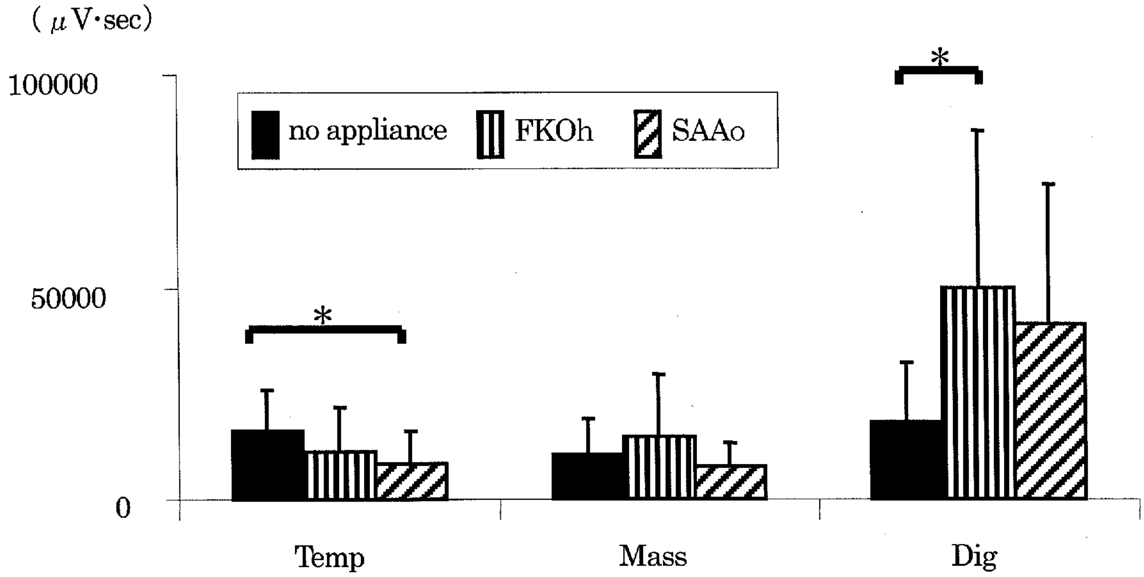


Figure 6. Muscle activity with and without the appliances during daytime
* : significantly different (p<0.05)

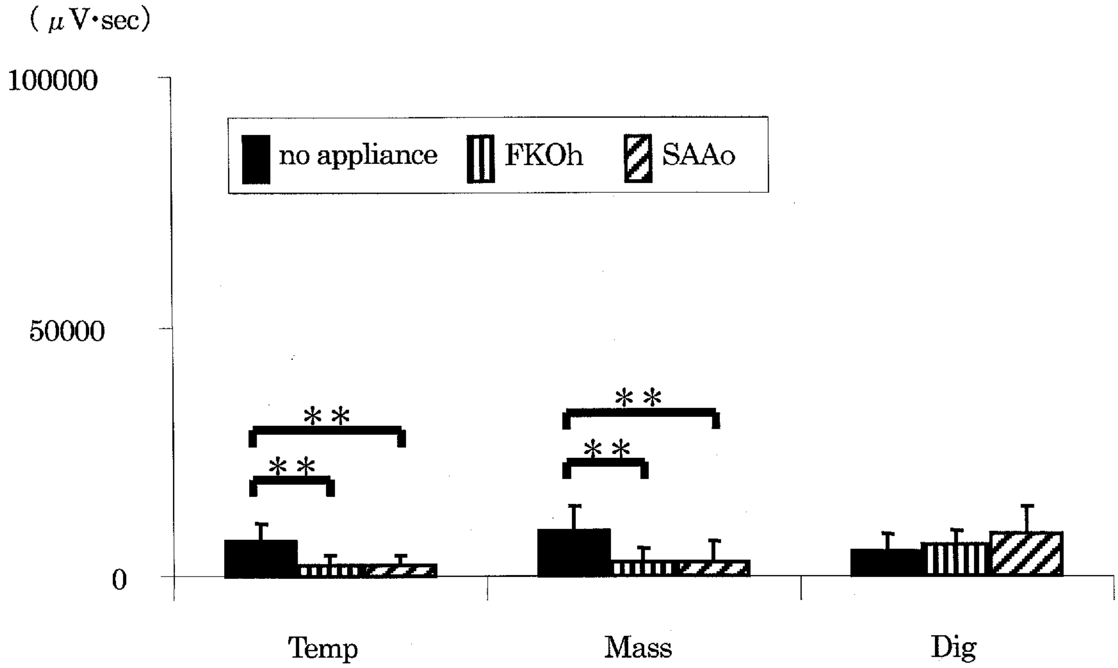


Figure 7. Muscle activity with and without the appliances during sleep
* * : significantly different (p<0.01)

3.3 Muscle activity with and without the appliances during voluntary biting under unconscious condition

Fig. 8 shows the integrated muscle activity in the temporal, masseter and digastric muscles during conscious biting with and without the appliances. During use of SAAo, the activity of temporal muscle was significantly decreased in comparison with that without the appliance ($p<0.05$), whereas the digastric muscle activity significantly increased with the use of FKOh as compared to that with SAAo and no appliance. For the masseter muscle, meanwhile, the mean integrated values were almost approximate with and without the three appliances.

As the influences of SAAo and SAAa on muscle activity, when comparing SAAo and SAAa, the activity of all three muscles with SAAa tended to be larger than that with SAAo (Fig. 9).

Moreover, the activity of temporal and masseter muscles during biting was extremely greater than that during daytime and sleep regardless of wearing the appliances, while the differences were not so substantial in the digastric muscle during biting and daytime (Fig. 10).

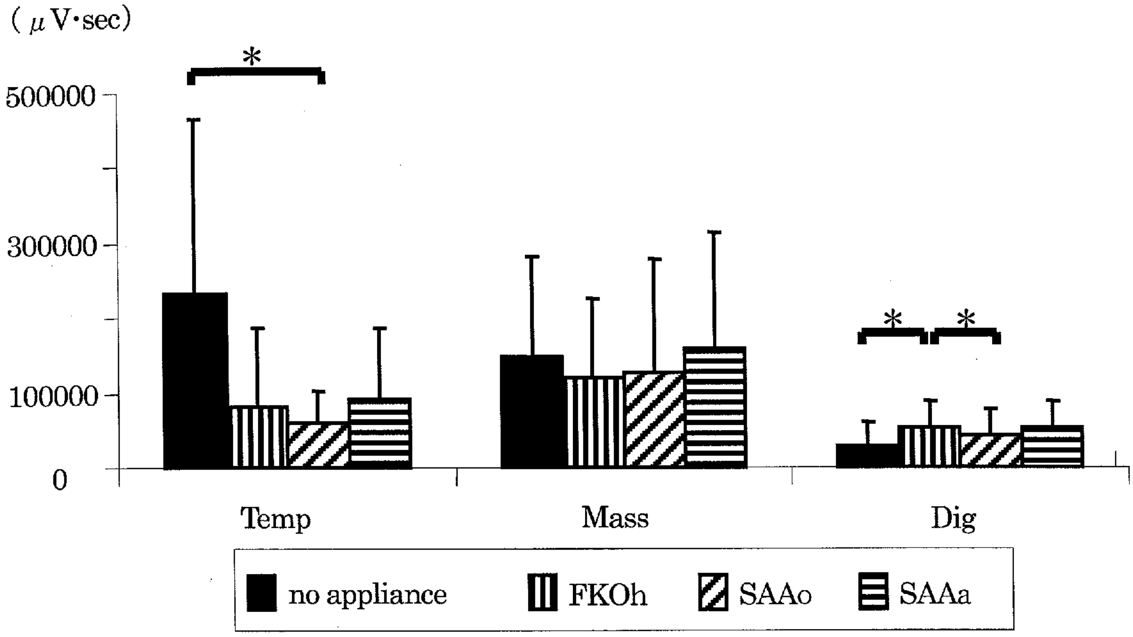


Figure 8. The mean integrated values of muscle activity in the temporal, masseter and digastric muscles during conscious biting with and without the appliances

* : significantly different ($p<0.05$)

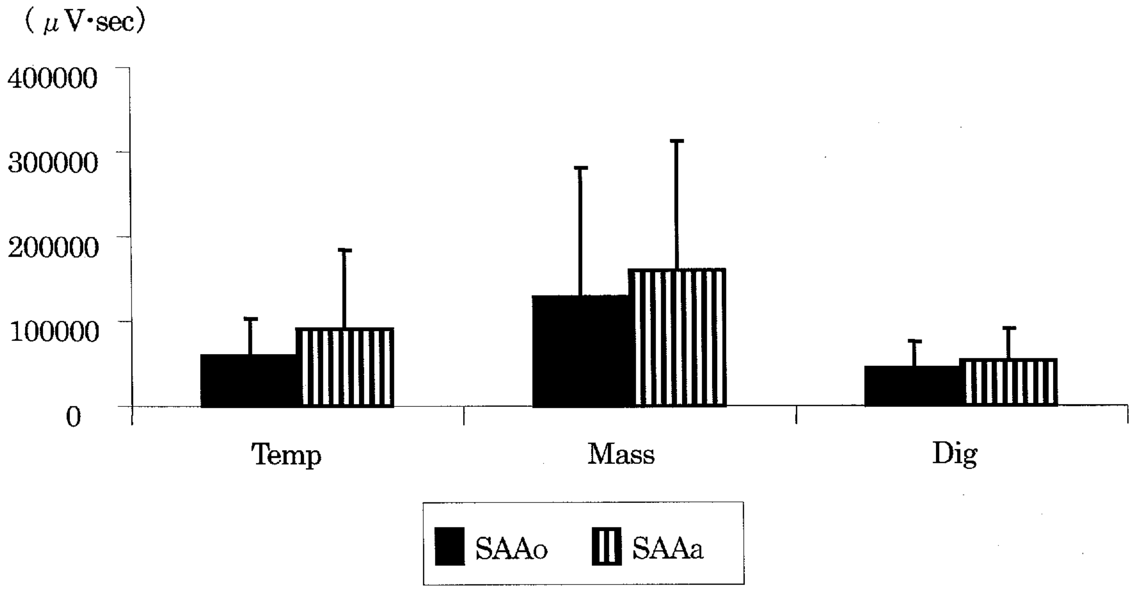


Figure 9. Comparison of integrated muscle activity with the use of SAAo and SAAa

The activity of all three muscles with SAAa tended to be larger than that with SAAo.

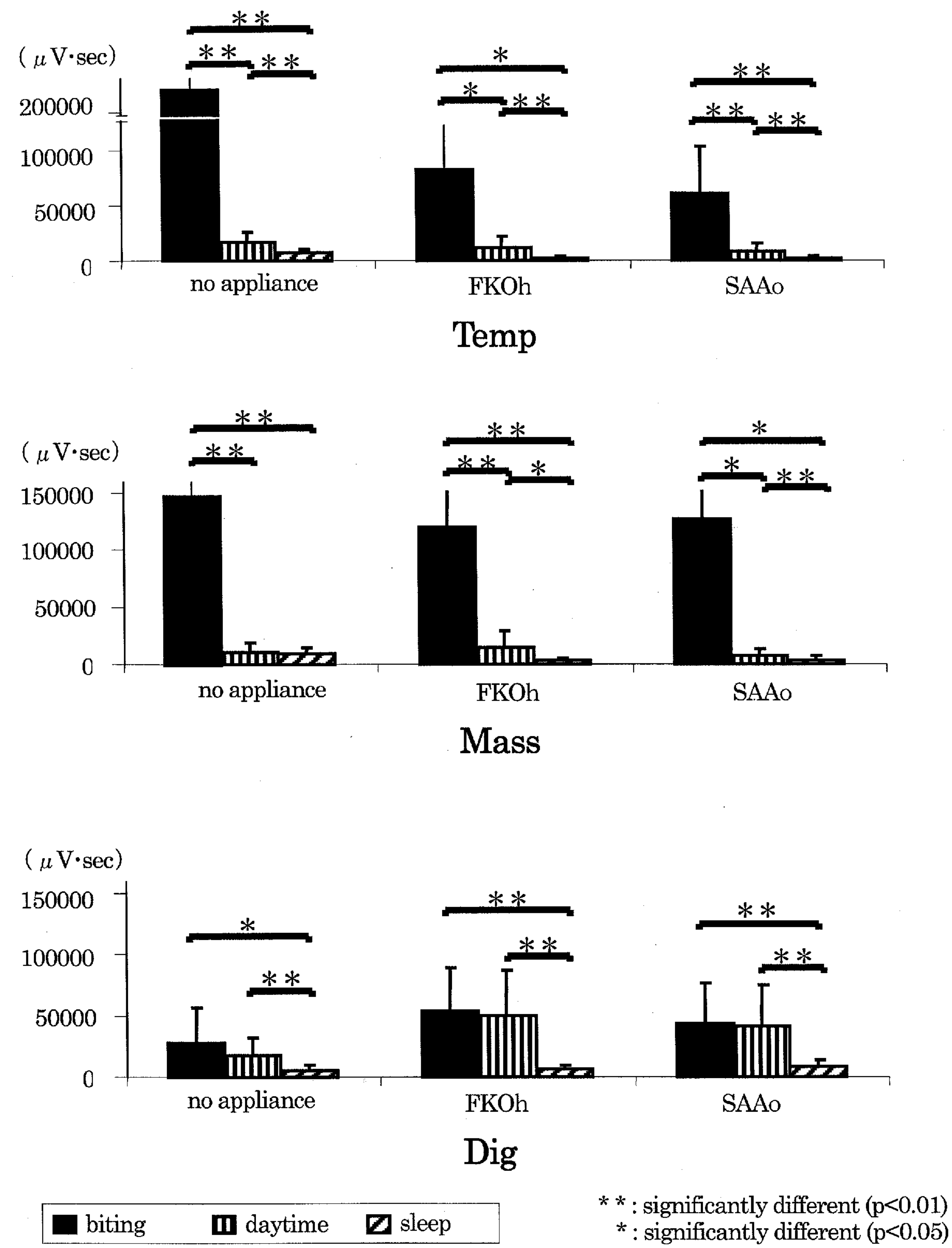


Figure 10. Comparison of integrated muscle activity among during biting, daytime, and sleep

The activity of temporal and masseter muscles during biting was extremely greater than that during daytime and sleep regardless of wearing the appliances, while the differences were not so substantial in the digastric muscle.

3.4 T/M ratio

Without the use of appliance, mean ratio of the temporal muscle activity to the masseter muscle (T/M) during sleep was significantly smaller than during daytime and biting.

With use of the appliances, the means of T/M ratios increased during daytime and sleep, however, the significant decrease was found during biting (Table 2).

Thus, the mean T/M ratios became the lowest when the appliances were used with voluntary biting, indicating that the masseter muscles exert a greater work than the temporal muscle in this condition. Since Niide (1986) reported that T/M ratio, which may be associated with morphology or growth of mandible, was higher in open bite than in the controls for both children and adults, smaller T/M ratios produced by the voluntary biting with the appliances in use would be more optimal for accelerating forward mandibular growth by use of the functional appliances.

Table 2: Mean ratio of the temporal muscle activity to the masseter muscle (T/M)

	T/M ratio			
	No appliance	FKOh	SAAo	SAAa
biting	1.9±1.5	0.6±0.3 *	0.8±0.7 *	0.7±0.6 *
sleep	0.8±0.4 * (vs biting)	1.1±1.2	1.0±0.5	
daytime	1.9±1.2 ** (vs sleep)	3.6±6.6	2.8±4.4	

* * : significantly different (p<0.01)
* : significantly different (p<0.05)

3.5 Mandibular displacement with the activator and SAA

Fig. 11 shows the amount of mandibular displacement at the lower central incisor and first molar when FKOh and SAAo are used. For the incisal and molar points, SAAo presented significantly larger mandibular displacement than FKOh in all the directions. Since SAAo is more mobile itself due to the connected wire springs, the muscles exhibit active contraction in the isotonic condition at the construction bite.

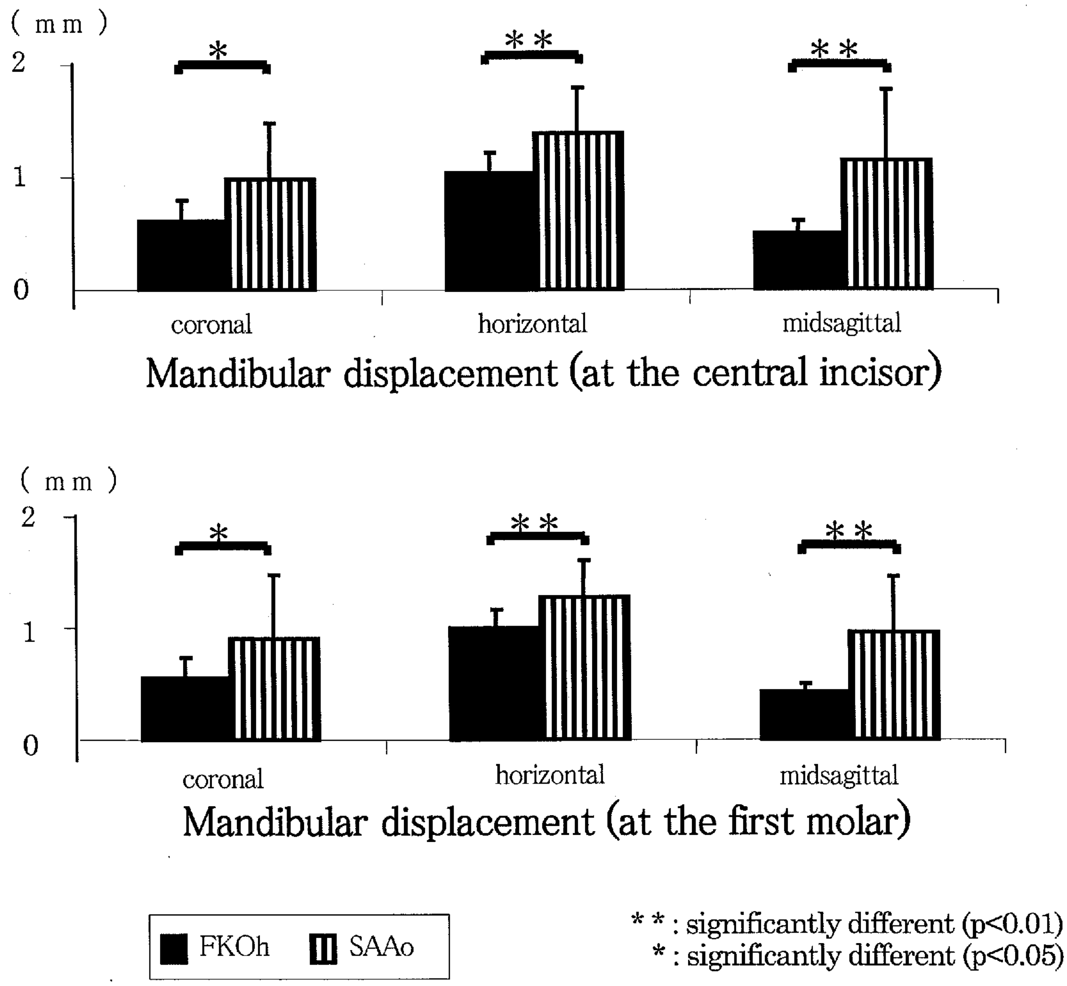


Figure 11. The amount of mandibular displacement at the lower central incisor and first molar

4. Discussion

4.1 Methodology in the present study

A few studies investigated masticatory muscle activity induced by various functional orthodontic appliances including the similar functional appliances to SAA (Akkaya et al. 2000), however, the recordings were usually executed during clenching or swallowing for a limited time in the laboratory. Meanwhile, for elucidating the response of masticatory muscle to these appliances, it is of an importance to record muscle activity not only for a short time, but also for a long period.

With these considerations, the present study was designed to establish two recording conditions for muscle activity with EMG. At first, masticatory muscle activity was recorded for a long period during daytime and sleep with and without functional appliances. Secondly, EMG activity of the masticatory muscles was recorded while biting with and without the appliances. It is assumed that muscle activity from voluntary biting is a conscious task, whereas muscle activity with or without the use of appliances during daytime and sleep is generated unconsciously. In orthodontic clinic, we sometimes instruct patients to bite the appliance during the daily use. Such a two-way use of the appliance might produce differences in the sum total of integrated muscle activity or balance of the elevator muscle activity. Thus, T/M ratio was used to estimate the balance of temporal and masseter muscle activity in this study.

With a portable EMG recording system used in the present study, various cumbersome things due to normally occurred motion interference in field measurements have been solved using a state-of-the-art amplification technology in which the amplifier is connected directly to the ground electrode. This technology effectively eliminates noises caused by disturbances such as body movements and retains EMG signals (Saifuddin et al. 2001; Hiyama et al. 2002). Therefore, it is confirmed that actual EMG activities can be much more accurate with this portable EMG recording unit than with conventional ones.

Functional appliances, in general, are used for growing Class II patients to modulate mandibular growth with small and/or retropositioned mandible. However, from an experimental standpoint, it is considered to be difficult to employ children as the subjects for the repeated recording for such a long time as consecutive 220 minutes quietly and following instructions, during daytime in particular. Moreover, it is obvious that individual differences in muscle activity due to various factors are greater in children than in adults. So far, no studies have been executed with children in such condition during daytime, although Noro (1991) executed long-time recordings with children during sleep. Therefore, subjects in the present study were selected in healthy adult males. However, we performed a short-time EMG recording similar to the present study for two young patients (ten-year-old girls), and confirmed that the result of the recording mostly supported the present findings with major interests (Table 3).

Table 3: EMG recording data of two young patients (ten-year-old girls) for a short time

(unit: μV・sec)

			no appliance	activator
Subject a	daytime	Temp	88080	29420
		Mass	56880	37140
		Dig	119100	125960
	sleep	Temp	24500	21640
		Mass	11180	54460
		Dig	79880	84460
	biting	Temp	168620	82940
		Mass	94980	127920
		Dig	119280	140200

			no appliance	activator	SAA	SAA activated
Subject b	daytime	Temp	59340	58400	218420	
		Mass	19700	219320	317580	
		Dig	56480	149800	136680	
	sleep	Temp	27520	21760	156220	
		Mass	11320	146360	290120	
		Dig	57560	152020	145860	
	biting	Temp	178340	56560	210940	239520
		Mass	84260	222820	329300	318640
		Dig	47460	171460	163700	173940

<note>

①The activity of all muscles during biting tended to be greater than that during daytime and sleep. ②The muscle activities tended to increase in the digastric muscle and to decrease in the temporal muscle with activators in all three conditions. ③The T/M ratios tended to be lower with the biting use of appliances.

4.2 Changes in integrated muscle activity with functional appliances under unconscious condition during daytime and sleep

During sleep, decrease in the temporal and masseter muscle activities were found in response to the use of functional appliances. The activities of the temporal and masseter muscles was not stimulated by wearing the functional appliances, and indeed, nocturnal use of the appliances reduced activity of these muscles. This supports previously demonstrated findings that there was no increase in the postural EMG activity while in use of functional appliances or bite planes during sleep (Ahlgren 1960; Noro 1991; Noro et al. 1994; Hanakago 1996; Mise 1997; Hiyama et al. 2002). Even during daytime, no increases in the activities of these muscles, especially in the temporal, were found with the use of the appliances. This supports previous results that the use of functional appliances or bite planes at rest did not increase EMG activity of the temporal (Ahlgren 1960; Thilander and Filipsson 1966; Carlsson 1979; Auf der Maur 1980; Ingervall and Bitsanis 1986), the masseter muscles (Thilander and Filipsson 1966; Carlsson 1979; Ingervall and Bitsanis 1986; Mise 1997; Yamin-Lacouture et al. 1997), and the lateral pterygoid muscle (Auf der Maur 1980; Yamin-Lacouture et al. 1997). The reason why the decrease in the temporal muscle activity is induced by the appliance under unconscious condition might be explained by splint therapy. When activator is used and the elevator muscles are stretched beyond their static length, the active and total tension of their muscles is reduced. Ahlgren (1960) showed that EMG activity of the elevator muscles was reduced by wearing an activator as an immediate response of the appliance. In addition, most of the subjects may have discomfort or difficulties to produce contraction force in response to the appliances in use. In a biomechanical study for activator with a moderate construction bite height equivalent to free-way space plus 1-5mm, the force arms of the temporal muscle decreased by 8% during clenching (Ahlgren et al. 1982). Yoshida (1990) concluded that bite planes with varying vertical dimensions from 2.5 to 7.5mm decreased activity of the anterior portion of the temporal muscle but not the masseter muscle activity.

Recently, it is well understood that passive tension associated with viscoelasticity of soft tissues and tonic stretch reflex of muscles play an important role in the effect of functional appliances, rather than active contraction of the jaw closing muscles, because of much longer duration of forces from passive tension than from active contraction (Thilander and Filipsson 1966; Ahlgren 1970; Auf der Maur 1980; Graber and Neumann 1984; Woodside 1984; Ingervall and Bitsanis 1986; Sessel et al. 1990; Noro 1991; Noro et al. 1994). This effect of functional appliances with construction bite may associate with effect on condyle or glenoid fossa remodeling. In general, light continuous force is more effective for orthodontic tooth movement and craniofacial remodeling, based on cell kinetics for osteoclasts and osteobalsts. In association with the consideration, Harvold and Vargervik (1971) and Woodside et al. (1973) indicated that forces induced by passive tension were effective for the treatment of activator. They also proposed the use of modified activator with higher construction bite, and Noro (1991) supported that. The present study supports this hypothesis under unconscious conditions because of no increase in the activities of temporal and masseter muscles especially in temporal muscle with use of the appliances. Sessel et al. (1990) investigated muscle activity in juvenile monkeys with functional appliances. The appliances in use to induce mandibular protrusion produce reduction in postural EMG activity of the superior and inferior heads of the lateral pterygoid muscles, superficial portion of the masseter, and anterior portion of the digastric muscles. The reduction in the first three muscles was statistically significant. In spite of such decrease in muscle activity, the mandible exhibited substantial growth of 10mm anterior protrusion for wearing appliances continuously (Sessel et al. 1990).

One reason why T/M ratio with and without functional appliances became lower during sleep than during daytime might be related to the body position. It was reported that the temporal (Lund et al. 1970; Holmgren et al. 1985; Yoshida 1990) and digastric muscles (Lund et al. 1970; Yoshida 1990) showed decrease while the masseter muscle (Yoshida 1990) presented no changes with different body postures from sitting to supine position without appliances, which has been confirmed by the present study. In addition, with functional appliances, the same tendency that decrease of temporal muscle activity is more extensive than that of masseter muscle with different body postures from sitting to supine position may be indicated for the findings without the appliances.

The activity of digastric muscle was higher than that of masseter muscle during daytime without the use of appliances. On the contrary, masseter muscle presented higher activity than digastric muscle during sleep. The reason might be because the prevalence of occlusal contacts was reduced under unconscious condition during daytime. Masseter muscle activity thus became very low, and the digastric muscle exhibited large activity mainly during saliva swallowing, although it is well known that the frequency of saliva swallowing during sleep is very few (Lear et al. 1965). At the same time, masseter muscle activity without appliances showed no significant difference between daytime and sleep. The opposite result should thus be exhibited during sleep. Additionally, the digastric muscle activity increased by use of the appliances was more prominent during daytime than during sleep and biting. The increase in the activity might be produced by opening the mouth to displace the mandible and stimulate the muscle with the construction bite, moving of the tongue, or swallowing the increased salivary secretion resulting from the change in intraoral environment produced by wearing the appliances. These findings are in accordance with a few results examined under awaked state (Ahlgren 1960; Thilander and Filipsson 1966; Miralles et al. 1988). Ahlgren (1960) and Thilander and Filipsson (1966) found a marked increase in the suprahyoid muscle activity with activator in use. Miralles et al. (1988) also found a significant increase in the digastric muscle activity with activator in use.

4.3 Changes in integrated muscle activity with functional appliances under conscious condition during biting

When biting voluntarily between teeth without the appliances, the activity of temporal muscle was greater than that of masseter muscle. Meanwhile, masseter muscle activity was higher than temporal muscle activity which resulted in the significant decrease by the use of the appliances. Significantly lower activity of the temporal muscle while biting the appliances may be explained by the changes in muscle length resulting from the appliances in use. It may also be assumed that a great influence of the anterior and downward mandibular displacement on temporal muscle may directly produce a decrease in the muscle activity during biting the appliances. In contrast, construction bite with 3mm forward displacement of mandible and vertical distance of 8 mm at the incisors may affect masseter muscle activity less substantially due to occlusal contacts through the appliances during biting. Given these considerations, T/M ratio was significantly decreased by biting FKOh, SAAa, and SAAo in comparison with that without the appliance. In addition, when SAAo was used, the activity of temporal muscles became the least among the three conditions. Since the mandibular position is controlled by two springs which have mobility, construction bite in the SAAo seems to be more unstable than in FKOh. Thus, the reason that high activity could not be observed in the temporal muscle with SAAo might have some association with the structure of SAAo.

The appliances exert more substantial influence on the activity of temporal muscle than the masseter muscle during biting. These differences may be explained by the different roles of muscles. The masseter muscle may spend most of its time in biting or clenching, while the temporal muscle plays a dominant role in stabilizing the mandibular position (Latif 1957). Thus, it is confirmed that masseter muscle activity is induced less substantially compared with temporal muscle when the upper and lower teeth contact through the appliance in use between the dentitions especially during biting. It is also assumed reasonably that T/M ratio in use of the functional appliances during biting might became lower significantly than that under unconscious condition.

We found significantly higher activity of the digastric muscle with the appliances in use. It may be accepted reasonably that mouth opening is produced by the construction bite and salivary secretion is enhanced due to the intraoral mechanical stimulation with the appliance in the mouth even during biting.

When comparing SAAo and SAAa, the activity of all three muscles with SAAa tended to be more predominant than that with SAAo. Therefore, larger vertical activation of SAA on the molars may induce higher activity of masticatory muscles.

It has been proposed that the functional appliance should be used during daytime especially not at rest but in function to obtain better treatment results due to high activity of masticatory muscles (Thilander and Filipsson 1966; Miralles et al. 1988). Schmuth (1960) found greater intermittent jaw closing forces in Class II patients with successful results. Furthermore, several investigations have shown a correlation between masticatory muscle activity and craniofacial growth patterns or the morphology (Watt and Williams 1951; Tabe 1976; Beecher and Corruccini 1981; Kiliaridis et al. 1985; Niide 1986; Ingervall and Bitsanis 1987; Kiliaridis 1989; Ishizuka 1996; Ueda HM et al. 1998; Ueda HM et al. 2000). According to Ingervall and Bitsanis (1987), individuals with long-face have weak masticatory muscles, and if facial form is partly determined by the strength of the masticatory muscles, this could suggest therapeutic possibilities. Strengthening the masticatory muscles could have a beneficial effect on facial growth in long-faced children. They have also demonstrated a gradual increase in bite force and an increased anterior rotation during one year of muscle training. Suto et al. (1998) suggested that biting use of activator effects on short and long facial skeletal patterns to bring them closer to each other. Furthermore, according to Niide (1986), T/M ratio was higher in control children than in the control adults because children had immature masseter muscles, and T/M was higher in openbite than in the controls for both children and adults. From these suggestions, the decrease in T/M ratio by biting functional appliances may be associated with that strengthening the masticatory muscles, masseter muscle in particular, surely have a beneficial effect on forward mandibular growth.

On the other hand, a conventional usage of activator especially for long-face cases sometimes may result in a clockwise rotation of mandible, and/or little or no additional growth of the mandible with activator except for dentoalveolar changes (Jakobsson 1967; Harvold and Vargervik 1971; Woodside et al. 1973; Pancherz 1984; Hashim 1991). The reason may be associated with increase of T/M ratio, and decrease of jaw closing muscle activity which is resulted from mouth opening with the functional appliances in use during sleep or daytime at rest.

4.4 The activator and SAA

For incisal and molar points, SAAo presented significant larger mandibular displacement than FKOh in all the directions. Therefore, SAAo is proved in the present study to induce the significant mandibular displacement compared with FKOh even if during resting at the construction bite.

Comparing the muscle activities from FKOh and SAAo, any significant differences were not detected in the present study. However, during daytime, the mean integrated value of muscle activity with FKOh tended to be more predominant than that with SAAo. It is speculated that the difference in total muscle activity between FKOh and SAAo might have some association with differences in the isometric and isotonic contractions of muscles. When biting FKOh, masticatory muscle activity could be mainly observed as the isometric contraction. On the other hand, SAAo, which is proved to induce the significantly larger mandibular displacement than FKOh even if during resting, is more mobile itself due to the connected wire springs, therefore, the muscles exhibit active contraction in the isotonic condition at the construction bite. In the use of FKOh, biting force by the masseter muscle can be induced through the rigid mono-block appliance made of acrylic resin, and total muscle activity thus became high automatically even if biting strongly for a moment.

One of the most obvious differences between activator and SAA is that the shape of SAA is able to be changed. By increasing the height of molar part and use with biting, SAA may exert more effective orthodontic force than activator to correct dental and skeletal open bites with small and/or distally-located mandible, even if masticatory muscle activity and passive tension exerted with activator and SAA are equivalent.

4.5 Clinical implication

Recently, it is well accepted that passive tension associated with viscoelasticity of soft tissues and tonic stretch reflex plays an important role in the effect of functional appliances including on condyle or glenoid fossa remodeling, rather than active contraction of the jaw closing muscles. In general, light continuous force is more effective for therapeutic tooth movement and craniofacial remodeling. The present study supports the above concept because of no increase in the activities of temporal and masseter muscles, of which the former is more apparent with the use of appliances under unconscious conditions.

Meanwhile, we have found a considerable difference in the masticatory muscle activity with and without the use of functional appliances under conscious and unconscious conditions. Masticatory muscle activity was more predominant during voluntary biting than during daytime at rest and sleep, and exhibited the decrease in T/M ratio due to the construction bite of the appliances. Thus, we should pay a special attention to the effects of functional appliances on masticatory muscle activity in various daily situations. It is well known that craniofacial development is related with the activity of muscle and orofacial soft tissue must adapt easily and quickly to a new functional length and orientation. As we have already mentioned, it has been proposed that a functional appliance should be used during daytime, with voluntary biting action in particular, for better treatment results depending on higher activity of masticatory muscles. A correlation between masticatory muscle activity and craniofacial growth patterns has already been clarified. Therefore, the decrease of T/M ratio by biting functional appliances may be associated with that strengthening of the masticatory muscles, especially masseter muscle, and would surely have a beneficial effect on forward growth acceleration of the mandible.

Unfortunately, no significant differences in the muscle activity were found between the activator and SAA. However, with use of SAA during daytime in particular, it may be accepted that the patients could repeat to bite the appliance automatically, because the springs in SAA are activated by voluntary biting the appliance and swallowing saliva in frequent occasions. Such sequence following reflex response of the elevator and digastric muscles might be regarded as beneficial for the remodeling of dentoalveolar and craniofacial skeleton. Furthermore, by increasing the vertical height of posterior dentoalveolar region and use with biting, SAA may exert more effective jaw orthopedic force than activator to correct skeletal discrepancy with small and/or distally-located mandible.

Given these considerations, it is emphasized from the present study that the functional appliances should be used not only during sleep, but also during daytime if possible and combined with the voluntary biting to obtain the adaptation and development of the masticatory muscle for the "beneficial effect on facial growth" and the "re-training of the muscle" at a posttreatment mandible position, rather than simply for the "more mandible advancement" by high constriction of masticatory muscles.

5. Conclusions

The purpose of the present study was to evaluate the influences of activator and SAA on masticatory muscle activity, by means of recording EMG and mandibular movement.

Subjects in the present study were 12 healthy adult males (mean age: 26.6 years). They had almost normal skeletal relations and nearly complete dentition. Three appliances, FKOh, SAAo, and SAAa, were used for each subject. FKOh is an activator whose construction bite was taken at the edge to edge occlusion with 3mm forward displacement of the mandible and vertical distance of 8 mm at the incisors. SAAo had the same construction bite as FKOh. For the SAAa, the construction bite at the molar part was activated twice as much as SAAo. A digital EMG recording device and bi-polar silver silver-chloride electrodes were used to record the EMG from the right anterior temporal (Temp), superficial portion of the right masseter (Mass), and anterior belly of the right digastric muscles (Dig). The integrated EMG values were worked out. Furthermore, T/M ratio as the proportion of the temporal and masseter muscle activities was calculated for each session.

The present study consists of the following steps.

1) Long time EMG recording during daytime and sleep: The diurnal recording was carried out for consecutive 220 minutes with and without the use of FKOh and SAAo on three different days with an interval of one week. In the same day, nocturnal EMG recording was performed for 220 minutes again in their bed at the usual sleep posture. The analysis was executed for the stable 190 minutes.

2) Short time EMG recording during voluntary biting: All the subjects were requested to bite voluntarily in the intercuspal position, and with FKOh, SAAo, and SAAa between their teeth for 12 minutes in each session on the same day.

Each session was analyzed for the stable 9.5 minutes.

3) Measurement of mandibular displacement with the appliances in use: We recorded the displacement of two reference tracking points corresponding to the lower central incisor and right first molar with an optoelectronic jaw-tracking system. The maximum displacement was analyzed in each direction (coronal, horizontal, and midsagittal planes, which correspond to the Y-Z, X-Y, and Z-X planes) while using the appliances for 100 seconds.

Findings of the present study were shown as follows.

1. The activity of all muscles during biting was greater than that during daytime and sleep.
2. The muscle activities tended to increase in the digastric muscle and to decrease in the temporal muscle with activators in all three conditions.
3. The T/M ratios were lower with the biting use of appliances.
4. SAAo presented significantly larger mandibular displacement than FKOh in all the directions.

Given these findings, it is emphasized from the present study that the functional appliances should be used not only during sleep, but also during daytime if possible and combined with the voluntary biting to obtain the adaptation and development of the masticatory muscle for the "beneficial effect on facial growth" and the "re-training of the muscle" at a posttreatment mandible position, rather than simply for the "more mandible advancement" by high constriction of masticatory muscles.

6. Acknowledgements

This study was carried out in the Department of Orthodontics and Craniofacial Developmental Biology, Hiroshima University Graduate School of Biomedical Sciences, during 1999-2002.

I would like to express my most sincere gratitude and appreciation to Dr. Kazuo Tanne, Professor in the Department of Orthodontics and Craniofacial Developmental Biology, Hiroshima University Graduate School of Biomedical Sciences, for his gainfulness encouragement, wise advice, valuable suggestion, special care throughout my Ph.D. course at Hiroshima University.

Sincere thanks and appreciation are also extend to Prof. Yoshiki Shiba, Department of Oral Physiology, and Prof. Katsuyuki Kozai, Department of Pediatric Dentistry, Hiroshima University Graduate School of Biomedical Sciences for their valuable contribution to the completion of this research work.

My thanks and appreciation are due to my colleagues in the Department of Orthodontics and Craniofacial Developmental Biology, in particular Dr. Hiroshi M. Ueda, D.D.S., Ph.D. for his valuable supervision and expert advice.

Finally, I should also like to express my gratitude to my loved family for their support for the last four years.

7. References

Ahlgren J. An electromyographic analysis of the response to activator (Andresen-Häupl) therapy. Odontol Revy. 1960; 11: 125-151.

Ahlgren J. The neurophysiologic principles of the Andresen method of functional jaw orthopedics. A critical analysis and new hypothesis. Swed Dent J. 1970; 63: 1-9.

Ahlgren J. Early and late electromyographic response to treatment with activators. Am J Orthod. 1978; 74: 88-93.

Ahlgren J, Bendeus M. Changes in length and torque of the masticatory muscles produced by the activator appliance. A cephalometric study. Swed Dent J Suppl. 1982; 15: 27-35.

Akkaya S, Haydar S, Bilir E. Effects of spring-loaded posterior bite-block appliance on masticatory muscles. Am J Orthod Dentofac Orthop. 2000; 118: 179-183.

Andresen V, Häupl K. Funktionskieferorthopädie. Die grundlagen des Norwegischen system. Leipzig: JA Barth, 1936.

Auf der Maur HJ. Electromyographic recordings of the lateral pterygoid muscle in activator treatment of Class II, division 1 malocclusion cases. Eur J Orthod. 1980; 2: 161-171.

Beecher RM, Corruccini RS. Effects of dietary consistency on craniofacial and occlusal development in the rat. Angle Orthod. 1981; 51: 61-69.

Birkebaek L, Melsen B, Terp S. A laminagraphic study of the alterations in the temporo-mandibular joint following activator treatment. Eur J Orthod. 1984; 6: 257-266.

Bishara SE, Ziaja RR. Functional appliances: a review. Am J Orthod Dentofac Orthop. 1989; 95: 250-258.

Carels C, van der Linden FP. Concepts on functional appliances' mode of action. Am J Orthod Dentofac Orthop. 1987; 92: 162-168.

Carels C, van Steenberghe D. Changes in neuromuscular reflexes in the masseter muscles during functional jaw orthopedic treatment in children. Am J Orthod Dentofac Orthop. 1986; 90: 410-419.

Carlsson GE, Ingervall B, Kocak G. Effect of increasing vertical dimension on the masticatory system in subjects with natural teeth. J Prosthet Dent. 1979; 41:

284-289.

Eschler J. Die funktionelle Orthopädie des Kausystems. München: C Hawser, 1952.

Feeland TD. Muscle function during treatment with the functional regulator. Angle Orthod. 1979; 49: 247-258.

Freunthaller P. Cephalometric observations in Class II, division 1 malocclusions treated with the activator. Angle Orthod. 1967; 37: 18-25.

Graber TM, Neumann B. Removable Orthodontic Appliances. 2nd ed. Philadelphia: WB Saunders, 1984.

Grossman WJ, Greenfield BE, Timms DJ. Electromyography as an aid in diagnosis and treatment analysis. Am J Orthod. 1961; 47: 481-497.

Hanakago K. Changes in masseter muscle activity with the application of bite plate -By 24 hours masticatory muscle EMG-. J Kyusyu Dent Soc. 1996; 50: 349-361.

Harvold EP, Vargervik K. Morphogenetic response to activator treatment. Am J Orthod. 1971; 60: 478-490.

Hasim HA. Analysis of activator treatment changes. Aust Orthod J. 1991; 12: 100-104.

Herren P. The activator's mode of action. Am J Orthod. 1959; 45: 512-527.

Hiyama S, Ono T. Ishiwata Y, Kuroda T, McNamara JA Jr. Neuromuscular and skeletal adaptations following mandibular forward positioning induced by the Herbst appliance. Angle Orthod. 2000; 70: 442-453.

Hiyama S, Kuribayashi G, Ono T, Ishiwata Y, Kuroda T. Nocturnal masseter and suprahyoid muscle activity induced by wearing a bionator. Angle Orthod. 2002; 72: 48-54.

Holmgren K, Sheikholeslam A, Riise C. An electromyographic study of the immediate effect of an occlusal splint on the postural activity of the anterior temporal and masseter muscles in different body positions with and without visual input. J Oral Rehabil. 1985; 12: 483-490.

Imoto S, Nagakane N, Ueda H, Tanne K. Effects of spring active appliance (SAA) in high angle maxillary protrusion cases. J Chu-Shikoku Orthod Soc. 1997; 9: 46-54.

Ingervall B, Bitsanis E. Function of masticatory muscles during the initial phase of activator treatment. Eur J Orthod. 1986; 8: 172-184.

Ingervall B, Bitsanis E. A pilot study of the effect of masticatory muscle training on facial growth in long-face children. Eur J Orthod. 1987; 9: 15-23.

Ingervall B, Thüer U. Temporal muscle activity during the first year of Class II, division 1 malocclusion treatment with an activator. Am J Orthod Dentofac Orthop. 1991; 99: 361-368.

Iscan HN, Akkaya S, Koralp E. The effect of the spring-loaded posterior bite-block on the maxillo-facial morphology. Eur J Orthod. 1992; 14: 54-60.

Ishizuka Y. Influences of masticatory muscle activity on morphogenesis of the craniofacial skeleton: a study with 24-hour EMG in rats. J Hiroshima Univ Dent Soc. 1996; 28: 289-311.

Jakobsson SO. Cephalometric evaluation of treatment effect on Class II, division 1 malocclusions. Am J Orthod. 1967; 53: 446-457.

Jakobsson SO, Paulin G. The influence of activator treatment on skeletal growth in Angle Class II: 1 cases. A roentgenocephalometric study. Eur J Orthod. 1990; 12: 174-184.

Kaku M, Miyamoto K, Tanimoto Y, Kawasoko S, Kawata T, Tanne K. Effects of activator in patients with maxillary protrusion affected by the craniofacial morphology and maxillary lateral incisor inclination. J Chu-Shikoku Orthod Soc. 2000; 12: 58-61.

Kiliaridis S. Muscle function as a determinant of mandibular growth in normal and hypocalcaemic rat. Eur J Orthod. 1989; 11: 298-308.

Kiliaridis S, Engstörm C, Thilander B. The relationship between masticatory function and craniofacial morphology. 1. A cephalometric longitudinal analysis in the growing rat fed a soft diet. Eur J Orthod. 1985; 7: 273-283.

Kuster R, Ingervall B. The effect of treatment of skeletal open bite with two types of bite-blocks. Eur J Orthod. 1992; 14: 489-499.

Latif A. An electromyographic study of the Temporalis muscle in normal persons during selected positions and movements of the mandible. Am J Orthod. 1957; 43: 577-591.

Lear CS, Flanagan JB, Moorrees CFA. The frequency of deglutition in man. Arch Oral Biol. 1965; 10: 83-89.

Lund P, Nishiyama T, Møller E. Postural activity in the muscles of mastication with the subject upright, inclined, and supine. Scand J Dent Res. 1970; 78: 417-424.

McNamara JA Jr. Neuromuscular and skeletal adaptations to altered function in the orofacial region. Am J Orthod. 1973; 64: 578-606.

McNamara JA Jr, Carlson DS. Quantitative analysis of temporomandibular joint adaptations to protrusive function. Am J Orthod. 1979; 76: 593-611.

McNamara JA Jr, Hinton RJ, Hoffman DL. Histologic analysis of temporomandibular joint adaptation to protrusive function in young adult rhesus monkeys (Macaca mulatta). Am J Orthod. 1982; 82: 288-298.

Meach CL. A cephalometric comparison of bony profile changes in Class II, division 1 patients treated with extraoral force and functional jaw orthopedics. Am J Orthod. 1966; 52: 353-370.

Miralles R, Berger B, Bull R, Manns A, Carvajal R. Influence of the activator on electromyographic activity of mandibular elevator muscles. Am J Orthod Dentofac Orthop. 1988; 94: 97-103.

Mise Y. Effects of increase in interarch distance on masseter muscle activity -By 24-hour masticatory muscle EMG-. J Kyusyu Dent Soc. 1997; 51: 295-311.

Miyakawa T, Morinushi T, Kishimoto T, Ogura T. Examination in regard to the applied status and effects on the biting type FKO. Jpn J Pedodontics. 1998; 36: 593-603.

Niide J. A study of dentofacial and masticatory functional characteristics in anterior open bite children and adults. J Jpn Orthod Soc. 1986; 45: 38-47.

Noro T. Orthodontic forces exerted by activators. J Osaka Univ Dent Soc. 1991; 36: 78-104.

Noro T, Tanne K, Sakuda M. Orthodontic forces exerted by activators with varying construction bite heights. Am J Orthod Dentofac Orthop. 1994; 105: 169-179.

Pancherz H, Anehus-Pancherz M. Muscle activity in Class II, division 1 malocclusions treated by bite jumping with the Herbst appliance. An electromyographic study. Am J Orthod. 1980; 78: 321-329.

Pancherz H, Anehus-Pancherz M. The effect of continuous bite jumping with the Herbst appliance on the masticatory system: a functional analysis of treated Class II malocclusions. Eur J Orthod. 1982; 4: 37-44.

Pancherz H. A cephalometric analysis of skeletal and dental changes contributing to Class II correction in activator treatment. Am J Orthod. 1984; 85: 125-134.

Read MJF, Orth D. The integration of functional and fixed appliance treatment. J Orthod. 2001; 28: 13-18.

Ruf S, Baltromejus S, Pancherz H. Effective condylar growth and chin position changes in activator treatment: a cephalometric roentgenographic study. Angle Orthod. 2001; 71: 4-11.

Saifuddin M, Miyamoto K, Ueda HM, Shikata N, Tanne K. A quantitative electromyographic analysis of masticatory muscle activity in usual daily life. Oral Dis. 2001; 7: 94-100.

Sander FG. Biomechanical aspects of the spring-active-appliance during the night sleep. Prakt Kieferorthop. 1991; 5: 17-28.

Sander FG, Weinreich A. Die Unterkieferbewegungen während der Belastung. Prakt Kieferorthop. 1990; 4: 95-108.

Sander FG, Wichelhaus A. Der Federaktivator -erste Behandlungsergebnisse und Klinisches Falebeispiel. Prakt Kieferorthop. 1989; 3: 241-248.

Schmuth G. Muskeltätigkeit und Muskelwirkung im Rahmen der Funktionskieferorthopädie. Deutsch Zahn Mund Kieferheilkd. 1960; 32: 4-21 and 124-147.

Selmer-Olsen R. En kritisk betraktning over "Det norske system." Nor Tannlaegefor Tid. 1937; 47: 85-91, 134-142, and 176-193.

Sessle BJ, Woodside DG, Bourque P, Gurza S, Powell G, Voudouris J, Metaxas A, Altuna G. Effect of functional appliances on jaw muscle activity. Am J Orthod Dentofac Orthop. 1990; 98: 222-230.

Stellzig A, Steegmayer-Gilde G, Basdra EK. Elastic activator for treatment of open bite. Br J Orthod. 1999; 26: 89-92.

Suto M, Kuroe K, Okamoto C, Kim JH, Ito G. Facial skeletal patterns of maxillary protrusion and effects of the biting type FKO on their growth changes in pubescent girls. Orthod Waves. 1998; 57: 50-57.

Tabe T. A study on the activities in the masticatory muscles and the morphology of the orofacial skeleton. II. The correlation between the activities in the masseter muscles and the biting force, and the morphology of the orofacial skeleton. J Jpn Orthod Soc. 1976; 35: 255-265.

Tallgren A, Christiansen RL, Ash M Jr, Miller RL. Effects of a myofunctional appliance on orofacial muscle activity and structures. Angle Orthod. 1998; 68: 249-258.

Tangel DJ, Mezzanotte WS, Sandberg EJ, White DP. Influences of NREM sleep on the activity of tonic vs. inspiratory phasic muscles in normal men. J Appl Physiol. 1992; 73: 1058-1066.

Thilander B, Filipsson R. Muscle activity related to activator and intermaxillary traction in Angle Class II, division 1 malocclusions. An electromyographic study of the temporal, masseter and suprahyoid muscles. Acta Odontol Scand. 1966; 24: 241-257.

Tokiwa H, Kuwahara Y. Clinical examination for stomatognathic functions -By using Gnatho-hexagraph-. J Jpn Prosthodont Soc. 1998; 42: 902-912.

Ueda HM, Ishizuka Y, Miyamoto K, Morimoto N, Tanne K. Relationship between masticatory muscle activity and vertical craniofacial morphology. Angle Orthod. 1998; 68: 233-238.

Ueda HM, Miyamoto K, Saifuddin M, Ishizuka Y, Tanne K. Masticatory muscle activity in children and adults with different facial types. Am J Orthod Dentofac Orthop. 2000; 118: 63-68.

Umehara Y. An experimental study on the functional jaw orthopedics (I). J Stomatol Soc. 1941; 15: 482.

Uner O, Darendeliler N, Bilir E. Effects of an activator on the masseter and anterior temporal muscle activities in Class II malocclusions. J Clin Pediatr Dent. 1999; 23: 327-332.

Watt DG, Williams CHM. The effects of physical consistency of food on the growth and development of the mandible and maxilla of the rat. Am J Orthod. 1951; 37: 895-928.

Wichelhaus A, Sander FG. Der Federaktivator -eine neue Therapiemöglichkeit für die Behandlung des offenen Bisses. Prakt Kieferorthop. 1989; 3: 235-240.

Woodside DG. The Harvold-Woodside activator. In: Graber TM, Neumann B, eds. Removable Orthodontic Appliances. 2nd ed. Philadelphia: WB Saunders, 1984: 244-309.

Woodside DG, Metaxas A, Altuna G. The influence of functional appliance therapy on glenoid fossa remodeling. Am J Orthod Dentofac Orthop. 1987; 92: 181-198.

Woodside DG, Reed RT, Doucet JD, Thompson GW. Some effects of activator treatment on the growth rate of the mandible and position of the midface. In: Cook JT, ed. Transaction of the 3rd International Orthodontic Congress. 1st ed. London: Crosby Lockwood Staples, 1973: 459-480.

Yamin-Lacouture C, Woodside DG, Sectakof PA, Sessle BJ. The action of three types of functional appliances on the activity of the masticatory muscles. Am J Orthod Dentofac Orthop. 1997; 112: 560-572.

Yoshida M. Influences of changing vertical dimension, occlusal contacts of bite plane and body position on masticatory muscle activities. J Osaka Univ Dent Soc. 1990; 35: 287-306.

Yoshida S, Ueda H, Tanne K. Treatment effect of headgear and activator in adolescent skeletal 2 cases with open bite. J Hiroshima Univ Dent Soc. 2001; 33: 62-66.

Yuen SW, Hwang JC, Poon PW. Changes in power spectrum of electromyograms of masseter and anterior temporal muscles during functional appliance therapy in children. Am J Orthod Dentofac Orthop. 1990; 97: 301-307.