Electromyographic Activity of Masticatory Muscles in Different Skeletal Profiles

Srikanth Gunturu[1*], Sushmitha R. Tauro[2]

[1]Assistant professor, Dept. of Oral and Maxillofacial Surgery, A. B. Shetty Memorial institute of dental Sciences, Mangalore, Karnataka, INDIA.

[2]Professor, Sri Aurobindo College of dentistry and P G Institute, Indore, Madhya Pradesh, INDIA.

[*]Corresponding Address:

srik05@gmail.com

Research Article

Abstract: **Introduction:** Effects of activity of facial and masticatory muscles on facial morphology is important to understand the normal growth and morphological abnormalities If muscle function plays a role in the development, abnormal muscle function explain's certain abnormalities of facial morphology and certain forms of malocclusion. The present study is designed to know the activity of masticatory muscles in different skeletal facial profiles. **Method:** Fifteen subjects were selected who have acceptable occlusion and classified into Class I, Class II , Class III groups based on their cephalometric landmarks. Electromyographic recording of Masseter, Temporalis and Orbicularis Oris muscles were carried out and the activity of the muscles was correlated with their skeletal profiles. **Results:** Activity of the right and left muscles have not differed much. Postural EMG activity for masseter and Temporalis muscles were higher in class II subjects than in class I and class III subjects. Activity was lower in class I when compared to class II and class III. Orbicularis oris muscle activity is least in class II subjects during swallowing. High correlations between electromyographic activity and ANB angle were observed. **Conclusion:** Clear correlations were found between the shape of the face and the activity of the masticatory muscles.

Keywords: Skeletal facial type, Electromyography, Postural activity, ANB angle, Cephalometric land marks.

Introduction

The facial skeleton increases during the growth period in all three dimensions of space. The detailed mechanism by which the coordination and simultaneity of the enlargement of the face in the three planes are achieved is one of the fascinating things of nature. And numerous genetic and epigenetic factors influence this process of growth. All muscles that are attached to the mandible have an influence on its movements and position. The tension and force developed by a muscle changes with its length. This is highly significant in jaw muscles as the muscle length depends on normal space relations between upper and lower jaws. Muscles of the head are distinguished by their great variability. Muscles are variable not only to their strength but to their shape as well. It is important to know whether the activity of the facial and masticatory muscles has any effect on facial morphology in understanding the normal growth and possibly of morphological abnormalities. If muscle function plays a role in the development, abnormal muscle function explains certain abnormalities of facial morphology and certain forms of malocclusion. In order to understand the influences of masticatory muscle function on craniofacial morphogenesis, evaluation of the muscle activity in usual daily life is essential, because masticatory muscle function occurs all day long, not only during mealtimes. Such muscle activities, in general, may be rather weak in comparison to the activities during mastication or maximal voluntary clenching, but exert continuous stimuli on the bone and dentition. Both the intensity and duration of these stimuli on the bone and dentition may thus have an important role in the development of the craniofacial skeleton. Experiments have revealed a close interaction between craniofacial growth and changes in muscle morphology and function. Changes in size and shape of the craniofacial skeleton during growth may be related to the masticatory muscle function in daily life. The cross-sectional area of the masticatory muscle, evaluated by computed tomography, ultrasonography or magnetic resonance imaging, was also revealed to have a high correlation with the craniofacial morphology. The goal of orthognathic surgery is to create the harmony of dentofacial morphology and oral function. This goal cannot be achieved without a sufficient understanding of the aetiology of both disharmony and malocclusion. Many investigations have reported a close relationship between masticatory function and dentofacial morphology.

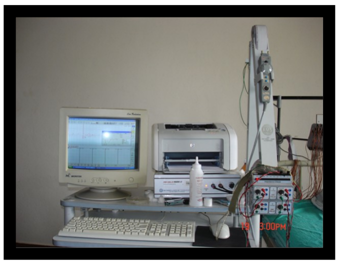
Material and Methods

The study group comprised of 15 individuals who had acceptable occlusions without any remarkable skeletal discrepancy. After explaining the aim of the experiment, informed consent was obtained from all of the subjects. The criteria for inclusion include Individuals with physiologic permanent dentition with no history of orthognathic surgery or orthodontic treatment, no cuspal interferences and no deviation of mandible. Individuals with missing teeth or prosthesis and individuals with TMJ or jaw muscle disorders are excluded. Cephalograms were used to classify the skeletal groups as shown in the table-1.

Table 1: Classification of subject groups

Skeletal group	ANB angle
Class I	0<ANB<4
Class II	ANB>4
Class III	ANB<0

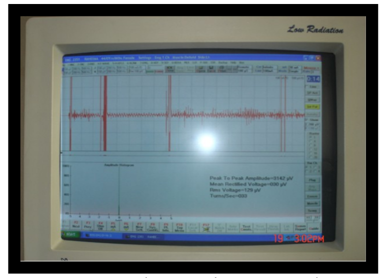
Neurocare 2000 EMG machine (Pic1), EMG/NCV/EP equipment which is fully computerized and windows based was used for the study.



Picture 1: Neurocare 2000, Biotech EMG machine

Electromyographic activity of muscles was measured using disc type silver chloride surface electrodes. Electrode was attached on the masseter muscle 1 cm above and below the motor point , on a line running parallel to the ear boarder (tragus) across the motor point. Temporalis muscle electrode was attached about 1 cm above the zygomatic arch and 1.5 cm behind the orbital border .Orbicularis oris muscle electrode was attached over the middle of the philtrum region. A large surface ground electrode was attached to the forehead for the recording of all the three muscles. The recording sites were cleansed and the electrodes were placed by applying a small amount of adhesive, on both the electrode and the skin surface. They were held in place using micropore plaster.The subjects, sitting upright in a chair with the frankfurt plane parallel to the floor as shown in pic.2. Separate set of readings were taken for the left and right side.

Picture 2: Subject positioning for EMG recording

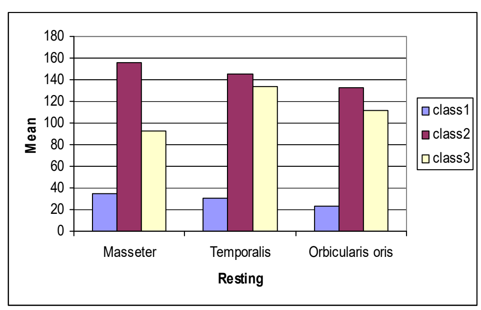


Picture 3: EMG observations over the monitor

After fixing the electrodes for one side the patient was asked to relax. The resting EMG potential was observed and recorded. Then patient was asked to swallow his saliva in a normal habitual pattern, the peak EMG activity was observed and recorded. The patient was then asked to make continuous chewing movements by giving MENTOS chewing gum. Peak EMG potentials were recorded (pic3). The mean values of the peak amplitude of the right and left muscles taken for the statistical analysis. Statistical analysis was done by using SPSS VER 15. To analyze whether statistical significance was present between Class I, Class II and Class III in various Jaw functions for different muscles, we have used KRUSKAL WALLIS TEST. Comparison between Class I versus class II, Class II versus Class III and Class I versus Class III and different muscles was analyzed using MANN-WHITNEY TEST. If p value was ≤ 0.05 it was considered to be statistically significant.

Results

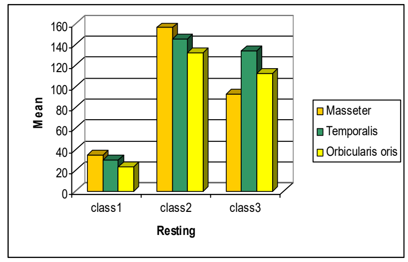
The 15 subjects were grouped equally into class I (5 subjects), class II (5 subjects) and class III (5 subjects) according to ANB angle. Variations in the ANB angle among the individual classes not considered in this study. Mean of EMG data for the right and left muscles recorded during each action of the mandible were considered, As there were no significant differences between the two sides. Mean amplitudes of masseter, Temporalis and orbicularis oris were compared in the resting state in various skeletal profiles (Graph.1)



Graph 1: Illustrating Peak amplitude of muscles during Resting among skeletal profiles

In the resting state higher peak amplitudes were observed in Class II skeletal profiles, followed by Class III. Least

EMG activities were observed in the Class I skeletal profiles. In class II skeletal profiles Masseter muscle activity was the highest, whereas in class III profiles Temporalis muscle activity was the highest (Graph.2). The differences in the muscle activities in different skeletal profiles were statistically highly significant (Table.2)



Graph 2: Illustrating Muscle activity in various skeletal profiles during Resting

Table.2 Mean peak amplitudes of masticatory muscles in various skeletal groups in resting

Position	Muscle	Class	Subjects	Mean	SD	H	P
Resting	Masseter	1.00	5	34.4	1.14018		
		2.00	5	155.8	21.17369		
		3.00	5	92.7	2.43926	12.545	0.002 hs
	Temporaiis	1.00	5	30.1	4.42154		
		2.00	5	144.9	6.05599		
		3.00	5	133.9	11.89222	10.238	0.006 hs
	Orbicularis Oris	1.00	5	23.6	7.16240		
		2.00	5	132.2	32.82073		
		3.00	5	112	5.87367	9.488	0.009 hs

The difference in mean amplitudes of muscle groups in class I and class II skeletal profiles in the resting position are significantly higher (p Value < .05) (Table.3)

Table 3: Comparison of muscle activities among Class I and Class II during resting

Resting –Class I Vs class II comparison

	Masseter	Temporalis	Orbicularis Oris
Z	-2.619	-2.619	-2.619
p-value	.009	.009	.009

Mean amplitudes of muscle groups in class I and class III skeletal profiles in the resting position are significantly higher (p Value < .005) (Table.4)

Table 4: Comparison of muscle activities among Class I and Class III during resting

Resting Class I vs class III Comparison

	Masseter	Temporalis	Orbicularis Oris
Z	-2.627	-2.619	-2.611
p-value	.009	.009	.009

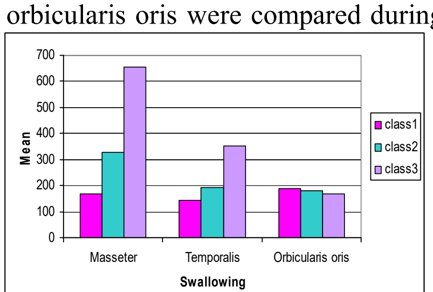
The amplitude differences between Temporalis and orbicularis oris muscles in the resting state are not significant among class II and class III. In other words significant difference of Temporalis and masseter muscle activities were not observed in class II and class III. (Table.5)

Table 5: Comparison of muscle activities among Class II and Class III during resting

Resting Class II Vs Class III comparison

	Masseter	Temporalis	Orbicularis Oris
Z	-2.619	-1.358	-.317
p-value	.009	.175	.751

Amplitudes of masseter, Temporalis and orbicularis oris were compared during swallowing in various skeletal profiles (Graph.3)



Graph 3: Illustrating Peak amplitude of muscles during swallowing among skeletal profiles

During swallowing higher peak amplitudes were observed for masseter in Class III skeletal profiles. The differences in the activities of masseter and Temporalis are highly significant in among class I, II & III profiles, Whereas orbicularis oris muscle activity is not significant in different skeletal profiles during swallowing. (Table.6)

Table 6: Mean peak amplitudes of masticatory muscles in various skeletal groups in swallowing

Position	Muscle	Class	Subjects	Mean	SD	H	P
Swallowing	Masseter	1.00	5	167.2	40.56723		
		2.00	5	325.5	220.23510		
		3.00	5	656	57.31056	8.780	0.012 hs
	Temporaiis	1.00	5	142.1	15.88395		
		2.00	5	193.7	32.64889		
		3.00	5	352.6	31.75768	11.180	0.004 hs
	Orbicularis Oris	1.00	5	190.2	85.51725		
		2.00	5	180.8	121.22170		
		3.00	5	166.8	8.78635	0.982	0.612 hs

The difference in mean amplitudes of muscle groups in class I and class II skeletal profiles during swallowing are significant only for Temporalis (p Value < .05). Among Masseter and orbicularis oris muscles activities no significant difference were observed (p Value < .05) (Table.7)

Table 7: Comparison of muscle activities among Class I and Class II during swallowing

Swallowing- class I vs class II Comparison

	Masseter	Temporalis	Orbicularis Oris
Z	-1.149	-2.611	-.104
p-value	.251	.009	.917

Among muscle groups in class I and class III skeletal profiles during swallowing no significant difference is observed with orbicularis oris. (p Value < .05) (Table.8)

Table 8: Comparison of muscle activities among Class I and Class III during swallowing

Swallowing class I vs class III Comparison

	Masseter	Temporalis	Orbicularis Oris
Z	-2.611	-2.611	-.524
p-value	.009	.009	.600

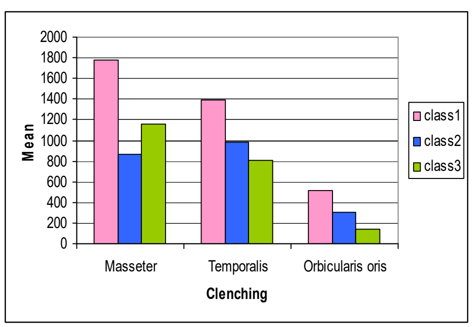
The amplitude differences of orbicularis oris muscle during swallowing is not significant between class II and class III. (Table.9)

Table 9: Comparison of muscle activities among Class II and Class III during swallowing

Swallowing Class II Vs Class III Comparison

	Masseter	Temporalis	Orbicularis Oris
Z	-2.193	-2.611	-.524
p-value	.028	.009	.600

Mean amplitudes of masseter, Temporalis and orbicularis oris muscles were compared during clenching (Graph.1)



Graph 4: Illustrating Peak amplitude of muscles during clenching among skeletal profiles

During clenching higher peak amplitudes were observed for Class I skeletal profiles for all the three muscles. Temporalis muscle activity is higher for the class II group than that of masseter and orbicularis oris (Graph..4). Highest masseter muscle activities were observed in Class I during clenching (Graph.5)

Graph 5: Illustrating Muscle activity in various skeletal profiles during clenching

The differences in the amplitudes of muscles among different skeletal profiles during clenching are statistically significant.(Table .10)

Table 10: Mean peak amplitudes of masticatory muscles in various skeletal groups in clenching

Position	Muscle	Class	Subjects	Mean	SD	H	P
Clenching	Masseter	1.00	5	1779.9	410.83808		
		2.00	5	867.6	159.56049		
		3.00	5	1162.9	109.14348	11.580	0.003 hs
	Temporaiis	1.00	5	1388.2	272.95709		
		2.00	5	977.1	339.53302		
		3.00	5	803.2	42.45233	7.033	0.03 sig
	Orbicularis Oris	1.00	5	519.6	262.03683		
		2.00	5	296.6	212.07381		
		3.00	5	141	5.47723	10.164	0.005 hs

The difference in mean amplitudes of muscle groups in class I and class II skeletal profiles during clenching are significant for masseter and Temporalis .Orbicularis oris activity is not statistically significant. (p Value < .005) (Table.11)

Table 11: Comparison of muscle activities among Class I and Class II during clenching

Clenching- class I vs class II Comparison

	Masseter	Temporalis	Orbicularis Oris
Z	-2.611	-1.984	-1.571
p-value	.009	.047	.116

The activity of orbicularis oris is not significant among class I and class III profiles (p Value < .05) (Table.12)

Table 12: Comparison of muscle activities among Class I and Class III during clenching

Clenching class I vs class III Comparison

	Masseter	Temporalis	Orbicularis Oris
Z	-2.611	-2.619	-1.786
p-value	.009	.009	.074

The amplitude differences between Temporalis and orbicularis oris muscles during clenching are not significant among class II and class III. In other words significant difference of Temporalis and masseter muscle activities were not observed in class II and class III during clenching. (Table.13)

Table 13: Comparison of muscle activities among Class II and Class III during clenching

Clenching class II Vs class III Comparison

	Masseter	Temporalis	Orbicularis Oris
Z	-2.193	-.524	-1.581
p-value	.028	.600	.114

At rest activity of masseter, Temporalis and Orbicularis is highest in class II subjects, Where as during swallowing masseter and Temporalis activities are highest in class III. Orbicularis oris activity is highest in class I during swallowing. During clenching highest activity is observed with class I profiles for masseter, Temporalis as well as orbicularis oris.

Discussion

There is less knowledge and more difference of opinion, on the question of why the bones of the head grow to their final size and form. It has been felt that the bones have an inherent potential to achieve their predetermined size and form, provided that pathological features do not intervene, and that function plays little part[18]. The functional aspect of growth has now come to the force again in a somewhat different light, particularly with the theories of Moss. Moss theory of the functional matrix postulates that the bones of the head grow in response to the function of two types of matrix, the periosteal matrix which includes the facial muscles and the teeth , and the capsular matrix, which includes the neural mass and the functional spaces of the mouth, nose and pharynx[19]. The periosteal matrix is responsible for altering the size and shape of the bones, capsular matrix alters spatial relationships between various parts of the head. He further postulated that it is the matrix which has the inherent potential for development, rather than the bones themselves. It would be unrealistic to regard the bones independently from their function. The bones are intimately concerned with the brain, the muscles, the teeth and the special sense organs, and it would be reasonable to assume that growth and development of all these components are interdependent[20]. In the light of present knowledge it would seem reasonable to believe that normal growth of head depends on the complex interrelationship of growth of all the components, including the function of the muscular components, with a large genetic element involved in both rates and timing of growth and in determination of final size and form[21]. Variation in the final form and size of the head falls into two broad categories, racial variation and individual variation. The different ethnic groups of mankind have a tendency to exhibit certain broad patterns of form of the skull and jaws, although such patterns are often overshadowed by individual variation. There is much individual variation within ethnic groups, possibly as a result of population mixture[22]. Variation in skull and jaw size and form between individuals is so common and so well known that it hardly needs description. It seems likely that such variation is largely genetically determined, and this view is supported by twin studies. Instructions for each muscle fiber to contract are delivered in the form of nerve impulses (action potentials) by cells located in brain stem motor nuclei for the masticatory muscles. Each muscle fiber contains only one neuromuscular junction. Sherrington pointed out that a single motor nerve fiber and the group of muscle fibers that it supplied could be considered as a functional unit because each time the nerve fiber discharged the muscle fibers that it innervates would contract; Sherrington described this functional unit as a motor unit[23]. When a motor unit is activated by a nerve impulse, the action potential is delivered to each muscle fiber of that unit by the alfa motor neuron. The membrane of each muscle fiber undergoes an electrochemical change, and as the fiber contracts it generates its own action potential. The action potentials from the active muscle fibers can be measured by Electromyography. The reproducibility of electromyograms has been extensively investigated in various studies[24]. Two major sources of variability appear to be electrode placement and variation in the subjects measured functional maneuvers. We tried to minimize this variability among individuals by selecting consistent reference points for electrodes placement. The source of variation of EMG also comes from the differences in age, body build, and sex. In this study we tried to minimize the age variation by choosing the specific age group, but body build and sex is not considered in this study. ANB angle, a widely used indicator of apical base relationship is compensated according to variations in maxillary position and rotation of the jaw and was used for skeletal classification in the present study. The results of the EMG recordings in the present study are in line with those reported by earlier studies[6, 11, 12, 14]. No difference in muscle activity was found with side, this may be due to the selection of symmetric faces. We found a positive correlation between the amplitude of the masticatory muscles examined. Intense activity of one of the muscles was associated also with intense activity of the other muscles during function. EMG activity for masseter and Temporalis muscles were higher in class II subjects than in class I and class III subjects. Activity was lower in class I when compared to class II and class III. These observations are different from those of Rodalfo Miralles who observed the highest activity in class III[5].

EMG activity of masseter and temporalis muscles during swallowing is higher in class III subjects than in class II and class I. This observation is same as that of Rodalfo Miralles[5]. Cross-sectional thickness of the muscles between different skeletal profiles differs[12]. Thickness of muscle is greater in short-faced subjects than in long-faced subjects. However the cross-sectional thickness of muscles is not considered in the present study. The activity of orbicularis oris muscle is highest in class II in the resting state and least in the class III subjects during swallowing this study. This can be explained by the fact that in lip incompetent subjects, the mandibular incisors were more protruded and the cant of mandibular plane was steeper than in the lip competent group. Md. Saifuddin et al observed considerable inter-individual variations in the normalized activities of masseter and temporalis muscles during usual daily life; this factor is not considered in our study[1]. However the differences in function of anterior and posterior portions of Temporalis muscles documented in various studies[4,5] have not been considered in the present study. The amplitudes during chewing varied clearly with shape of the face but no correlation with dentoalveolar variables was attempted in this study due to the fact that the individuals examined had clinically normal occlusion. In the present study clear correlations were found between muscle activity, which is a measure of muscle strength, and shape of the face.

Conclusion

In the present study clear correlations were found between muscle activity, which is a measure of muscle strength, and shape of the face. At rest activity of masseter, Temporalis and Orbicularis is highest in class II subjects, Where as during swallowing masseter and Temporalis activities are highest in class III . Orbicularis oris activity is highest in class I during swallowing. During clenching highest activity is observed with class I profiles for masseter, Temporalis as well as orbicularis oris. The development of the head and growth of the craniofacial skeleton are in no way simple matters. There is a growing body of evidence that the muscles of mastication influence the growth of the craniofacial skeleton. Abnormal muscle functional habits such as thumb sucking ,tongue thrusting influences the dentoalveolar component .Orthognathic surgery attempts to correct the abnormal skeletal facial profiles by altering the spatial relations of the bone there by affecting the muscles of mastication. But the longterm stability of surgical results will be dependent on the adaptation of these facial muscles to their final position .

Bibliography

1. Ueda HM, Miyamoto K, Saifuddin M, Ishizuka Y, Tanne K. Masticatory muscle activity in children and adults with different facial types. Am J Orthod Dentofacial Orthop. 2000 Jul; 118(1):63-8.
2. Lowe AA, Takada K. Associations between anterior temporal, masseter, and orbicularis oris muscle activity and craniofacial morphology in children. Am J Orthod. 1984 Oct; 86(4):319-30.
3. Harper RP, de Bruin H, Burcea I. Muscle activity during mandibular movements in normal and mandibular retrognathic subjects J Oral Maxillofac Surg. 1997 Mar;55(3):225-33.
4. Cha BK, Kim CH, Baek SH. Skeletal sagittal and vertical facial types and electromyographic activity of the masticatory muscle Angle Orthod. 2007 May; 77(3):463-70.
5. Miralles R, Hevia R, Contreras L, Carvajal R, Bull R, Manns A. Patterns of electromyographic activity in subjects with different skeletal facial types. Angle Orthod. 1991 Winter; 61(4):277-84.
6. Tecco S, Caputi S, Festa F. Electromyographic activity of masticatory, neck and trunk muscles of subjects with different skeletal facial morphology-a cross-sectional evaluation. J Oral Rehabil. 2007 Jul;34(7):478-86.
7. Rowlerson A, Raoul G, Daniel Y, Close J, Maurage CA, Ferri J, Sciote JJ. Fiber-type differences in masseter muscle associated with different facial morphologies. Am J Orthod Dentofacial Orthop. 2005 Jan;127(1):37-46.
8. Lim D, Beitzel F, Lynch G, Woods MG. Myosin heavy chain isoform composition of human masseter muscle from subjects with different mandibular plane angles. Aust Orthod J. 2006 Nov;22(2):105-14.
9. Throckmorton GS, Ellis E 3rd, Buschang PH. Morphologic and biomechanical correlates with maximum bite forces in orthognathic surgery patients. J Oral Maxillofac Surg. 2000 May;58(5):515-24.
10. García-Morales P, Buschang PH, Throckmorton GS, English JD. Maximum bite force, muscle efficiency and mechanical advantage in children with vertical growth patterns. Eur J Orthod. 2003 Jun;25(3):265-72.
11. van Spronsen PH, Weijs WA, van Ginkel FC, Prahl-Andersen B. Jaw muscle orientation and moment arms of long-face and normal adults. J Dent Res. 1996 Jun;75(6):1372-80.
12. van Spronsen PH. Masticatory muscles. Part V. Geometry of the masticatory muscles and cranial morphology. Ned Tijdschr Tandheelkd. 1997 Oct;104(10):373-6.
13. Pancherz H. Activity of the temporal and masseter muscles in class II, division 1 malocclusions. An electromyographic investigation. Am J Orthod. 1980 Jun;77(6):679-88.
14. Antonini G, Colantonio L, Macretti N, Lenzi GL. Electromyographic findings in Class II division 2 and Class III malocclusions. Electromyogr Clin Neurophysiol. 1990 Jan;30(1):27-30.
15. Pancherz H. Temporal and masseter muscle activity in children and adults with normal occlusion. An electromyographic investigation. Acta Odontol Scand. 1980;38(6):343-8.
16. Yuen SW, Hwang JC, Poon PW. EMG power spectrum patterns of anterior temporal and masseter muscles in children and adults. J Dent Res. 1989 May;68(5):800-4.
17. Deguchi T, Kumai T, Garetto L . Statistics of differential Lissajous EMG for normal occlusion and Class II malocclusion. Am J Orthod Dentofacial Orthop. 1994 Jan;105(1):42-8.
18. Moss ML. New studies of cranial growth. Birth Defects Orig Artic Ser. 1975;11(7):283-95.
19. Frankenhuis-van den Heuvel TH, Kuijpers-Jagtman AM, Maltha JC. Microscopic study of the rabbit mandibular periosteum and attached structures. Acta Anat (Basel). 1991;142(1):33-40.
20. Chan HJ, Woods M, Stella D. Mandibular muscle morphology in children with different vertical facial patterns: A 3-dimensional computed tomography study. Am J Orthod Dentofacial Orthop. 2008 Jan;133(1):10.e1-13.
21. van der Linden FP. Bone morphology and growth potential: a perspective of postnatal normal bone growth. Prog Clin Biol Res. 1985;187:181-200.
22. Katsaros C. Masticatory muscle function and transverse dentofacial growth. Swed Dent J Suppl. 2001;(151):1-47. Review.
23. Granata KP, Padua DA, Abel MF. Repeatability of surface EMG during gait in children. Gait Posture. 2005 Dec;22(4):346-50. Epub 2005 Jan 8.
24. Fulton JF, Sherrington CS. State of the flexor reflex in paraplegic dog and monkey respectively. J Physiol. 1932 May 30;75(1):17-22.
25. Takahashi S, Kuribayashi G, Ono T, Ishiwata Y, Kuroda T. Modulation of masticatory muscle activity by tongue position. Angle Orthod. 2005 Jan;75(1):35-9.
26. Michelotti A, Farella M, Vollaro S, Martina R. Mandibular rest position and electrical activity of the

masticatory muscles. J Prosthet Dent. 1997 Jul;78(1):48-53.
27. Nakakawaji K, Kodachi K, Sakamoto T, Harazaki M, Isshiki Y. Correlation between facial patterns and function of the masticatory muscles in girls and women. Bull Tokyo Dent Coll. 2002 May;43(2):51-9.
28. Satiroglu F, Arun T, Isik F. Comparative data on facial morphology and muscle thickness using ultrasonography. Eur J Orthod. 2005 Dec;27(6):562-7. Epub 2005 Aug 31.
29. Charalampidou M, Kjellberg H, Georgiakaki I, Kiliaridis S. Masseter muscle thickness and mechanical advantage in relation to vertical craniofacial morphology in children. Acta Odontol Scand. 2008 Feb;66(1):23-30.
30. Fogle LL, Glaros AG. Contributions of facial morphology, age, and gender to EMG activity under biting and resting conditions: a canonical correlation analysis. J Dent Res. 1995 Aug;74(8):1496-500.
31. Raadsheer MC, Kiliaridis S, Van Eijden TM, Van Ginkel FC, Prahl-Andersen B. Masseter muscle thickness in growing individuals and its relation to facial morphology. Arch Oral Biol. 1996 Apr;41(4):323-32.
32. Saifuddin M, Miyamoto K, Ueda HM, Shikata N, Tanne K. An electromyographic evaluation of the bilateral symmetry and nature of masticatory muscle activity in jaw deformity patients during normal daily activities. J Oral Rehabil. 2003 Jun;30(6):578-86.
33. Christensen LV. An electromyographic and cephalometric study on facial pains and facial morphology in children. J Oral Rehabil. 1981 May;8(3):267-77.
34. Tecco S, Caputi S, Festa F. Electromyographic activity of masticatory, neck and trunk muscles of subjects with different skeletal facial morphology--a cross-sectional evaluation. J Oral Rehabil. 2007 Jul;34(7):478-86.
35. Gallo LM, Gross SS, Palla S. Nocturnal masseter EMG activity of healthy subjects in a natural environment. J Dent Res. 1999 Aug;78(8):1436-44.
36. Lavigne GJ, Rompré PH, Poirier G, Huard H, Kato T, Montplaisir JY. Rhythmic masticatory muscle activity during sleep in humans. J Dent Res. 2001 Feb;80(2):443-8.
37. Kiliaridis S. Masticatory muscle influence on craniofacial growth. Acta Odontol Scand. 1995 Jun;53(3):196-202. Review.
38. Sinsel NK, Guelinckx PJ. Effect of unilateral partial facial paralysis on periosteal growth at the muscle-bone interface of facial muscles and facial bones. Plast Reconstr Surg. 2003 Apr 1;111(4):1432-43; discussion 1444-5.
39. Van Limborgh J. The role of genetic and local environmental factors in the control of postnatal craniofacial morphogenesis. Acta Morphol Neerl Scand. 1972 Oct;10(1):37-47.