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THE EFFECT OF ACTIVATOR TREATMENT OF SKELETAL CLASS 2 MALOCCLUSIONS ON THE TEMPOROMANDIBULAR JOINT REACTION FORCE

Prof. Dr. Oktay ÜNER

Asst. Prof. Dr. Nilüfer DARENDELİLER

Assoc. Prof. Dr. Haluk DARENDELİLER

ABSTRACT

A change in the pattern of condylar loading might lead to an increase in the amount of condylar/mandibular growth. In this study, the effect of activator treatment of skeletal Class 2 malocclusions on the magnitude and direction of the temporomandibular joint reaction force has been investigated. The treatment group for this study consisted of 12 patients, 8 girls and 4 boys, with an average age of 11.42 ± 0.29 years and skeletal age of 11.02 ± 0.29 years. An Andresen type activator was used for a mean period of 11 months. Electromyographic (EMG) activity of the masseter and anterior temporal muscles were measured and lateral cephalometric radiographs were taken at the beginning and at the end of the study. A two-dimensional model is described on the lateral cephalometric radiographs which uses the intregated EMG (IEMG) activity of the muscles and bite force as the input data and a computer program has been developed to calculate the magnitude and direction of the temporomandibular joint reaction force using this model. The differences of the magnitude and direction of the temporomandibular joint reaction force obtained at the beginning and at the end of activator treatment were compared with paired t-test but not found to be statistically significant.

Key words: *Activator, TMJ Reaction force, Electromyographic activity, Masticatory muscles.*

ÖZET: SINIF 2 MALOKLUZYONLU BİREYLERDE AKTİVATÖR TEDAVİSİNİN TEMPOROMANDİBULAR EKLEM REAKSİYON KUVVETİ ÜZERİNE ETKİSİ

Kondilin yüklenme modelinde bir değişiklik kondiler büyüme miktarında bir artışa neden olabilmektedir. Bu çalışmanın amacı sınıf II malokluzyona sahip bireylerin aktivatör tedavisi ile temporomandibular eklemin reaksiyon kuvvetinin değişimini incelemektir. Çalışmamızda ortalama kronolojik yaşları 11.42 ± 0.29 yıl ve ortalama iskelet yaşları 11.02 ± 0.29 yıl olan 8 kız 4 erkek toplam 12 birey tedavi kapsamına alındı. Bireyler ortalama 11 ay süre ile Andresen tipi aktivatör kullanmışlardır. Tedavi başı ve tedavi sonunda bireylerden lateral sefolometrik filmler elde edilmiş ve masseter ve anterior temporal kasın elektromyografik (EMG) kayıtları alınmıştır. Lateral sefolometrik filmler üzerinde iki boyutlu bir model tanımlanmış ve bu model kullanılarak çiğneme kas aktivitelerinin integre edilmiş değerleri ve ısırma kuvvetinin veri olarak girildiği bir bilgisayar programı geliştirilmiş ve temporomandibular eklem reaksiyon kuvvetinin büyüklüğü ve yönü hesaplanmıştır. Eklem reaksiyon kuvvetinin yönü ve büyüklüğünün aktivatör ile tedavisi başı ve tedavi sonrası değerler arası farkı istatiksel olarak önemli bulunmamıştır.

Anahtar Kelimeler: *Aktivatör, TME, Elektromyografik aktivite, Çiğneme kasları*

INTRODUCTION

Functional appliance treatment stimulates the mandibular growth and moves the mandible from centric relation to an eccentric position. Animal studies have shown stimulation of mandibular growth and altered condylar growth after forward repositioning of the condyles (1-4). However, differences exist regarding stimulation of mandibular growth using functional appliances in humans. Some studies support this opinion (5-7), whereas Björk (8), Harvold and Vargervik (9) and Wieslander and Largestrom (10) report no effect on mandibular growth with functional appliance therapy. Harvold and Vargervik (9) indicated that the changes of treatment were due to maxillary growth inhibition rather than mandibular growth stimulation.

Mechanical loading influences the remodelling of skeletal tissues. In the mandibular condyle, occlusal alterations and consequent mechanical stimulus induce changes in chondrocytes and cartilage mineralization (11). Accordingly, the direction and amount of loading affects both growth and adaptive response of the condyle (12,13). Considering the nature of the condyle developing from "secondary cartilage", it seems likely that the condyle is responding to the magnitude and direction of force. This corresponds to the orientation of cartilaginous growth plates toward compressive axial loading. The nonlinear arrangement of developing chondroblasts in the growing condyle may allow alignment in different directions with respect to the forces in the brachiofacial model and dolichofacial models. Cartilaginous growth enhances the occlusion and responds to condylar forces during growth. This might explain the unusual growth responses of condyles and in part describe the magnitude and direction of force on the temporomandibular joint. Haskell et al.(13) have shown how flexural stress in dysplastic types may influence the ultimate morphogenesis of the mandible as a result of the differential pattern in the direction and amount of loading forces on the body, ramus and temporomandibular joint, and found that the direction of condylar reaction force varied from a vertical orientation in the hyperdivergent model to oblique in the hypodivergent model. Birkebaek et al.(14) have shown that the growth direction of condyle in the centric position was different in a control group and in an activator group.

The most important factor which initiates the adaptive response in the temporomandibular region may be the change in the biomechanical and biophysical environment of the joint produced by either muscular or nonmuscular forces (15). Navarro et al.(16) and Pirttiniemi and Kantomaa (17) have evaluated the effect of muscles and Gazit et al.(18) quantified the effect of occlusal stimulus on the adaptive response of condyle. The continuity and duration of the applied pressure on the temporomandibular joint are also critical. Functional loading might modulate the rate of condylar growth and hence the overall length of the mandible (12). It is stated that a decrease in the functional loading on the condyle related to normal joint functions results in adaptive growth as protrusive mandibular motions (15,19,20).

Functional appliance therapy increases condylar growth by affecting the masticatory muscles, unloading of the temporomandibular joints and/or protrusion the condyles (15,21-23). Whilst lateral pterygoid traction is one means by which the pattern of loading could be changed (24) other muscles such as parts of masseter, medial pterygoid and temporal muscle might be able to produce the same degree of loading (15,25). Thus, condylar growth would be a function of the pattern of condylar loading. The objectives of the study are (1) to determine the change in the temporomandibular joint reaction force created by masseter and anterior temporal muscles before and after the activator treatment, and (2) to develop a two-dimensional mathematical model based on vector algebra for easy and accurate data input from lateral cephalograms, since in vivo measurement of temporomandibular joint forces is not possible in human subjects.

MATERIALS AND METHODS

The treatment group used for this study consisted of 12 patients, 8 girls and 4 boys, with an average age of 11.42 ± 0.29 years and skeletal age of 11.02 ± 0.29 years. The lateral cephalometric and hand-wrist radiographs were taken before and after treatment. The hand-wrist radiographs were assessed according to the method of Greulich and Pyle (26). Subjects having mandibular retrusion according to the results of the Sassouni analysis were selected. The patients were treated with the activator for 11 months and they used functional appliance 16 hours per day. The skeletal values of treatment group were showed Table 1. Electromyographic (EMG) activity of the masseter and anterior temporal muscles was recorded at the beginning and end of treatment.

A two-dimensional mathematical model based on vector algebra was developed to calculate the magnitude of the temporomandibular joint reaction force, F_J, and its direction by defining an angle θ with the x-axis (Fig. 1). The center of the coordinate system was selected as the center of the joint reaction and x-axis was drawn parallel to the occlusal plane. The lateral cepholograms taken at the beginning and end of treatment were used to determine the lines of action and direction of the masseter and anterior temporal muscle forces and bite force, $\mathbf{F}_M$, $\mathbf{F}_T$ and $\mathbf{F}_B$, respectively. The line of action of the anterior temporal force was assumed to extend from the deepest point of the concave of the anterior border of ramus to the tip of the coronoid process, and the line of action of the masseter muscle force was assumed to extend from gonion to the junction of the frontal and temporal processes along the posterior border of the zygomatic bone. The bite force was taken along a line perpendicular to occlusal plane and through the tip of the midpoint of molar. Coordinates of the arbitrarily selected points (x_{M1}, y_{M1}) and (x_{M2}, y_{M2}) on the line of action of the masseter muscle force, (x_{T1}, y_{T1}) and (x_{T2}, y_{T2}) on the line of action of the anterior temporal muscle force, and (x_{B1}, y_{B1}) and (x_{B2}, y_{B2}) on the line of action of molar bite force were measured on the lateral cephalograms to determine the unit vectors in the directions of the corresponding muscle forces and their moment arms (Fig. 1).

The forces applied by the masseter and anterior temporal muscles and the bite force can be written in terms of their magnitudes, F_M, F_T, and F_B, respectively, as follows

$$\mathbf{F}_M = F_M \mathbf{u}_M \quad (1)$$

$$\mathbf{F}_T = F_T \mathbf{u}_T \quad (2)$$

$$\mathbf{F}_B = F_B \mathbf{u}_B \quad (3)$$

where $\mathbf{u}_M$, $\mathbf{u}_T$, $\mathbf{u}_B$ are the unit vectors, which are in the direction of masseter and anterior temporal muscle forces and bite force, respectively. Bold letters indicate vectors whereas others show the scalars in the equations.

In static equilibrium, laws of the mechanics require that sum of the all moments about a point is zero and sum of the all forces is zero. Therefore, sum of the moments of the muscle forces about the center of joint reaction is

$$\sum \mathbf{M} = \mathbf{0} \quad (4)$$

and from Fig. 1

$$\mathbf{d}_M \times \mathbf{F}_M + \mathbf{d}_T \times \mathbf{F}_T + \mathbf{d}_B \times \mathbf{F}_B = \mathbf{0} \quad (5)$$

where $\mathbf{d}_M$, $\mathbf{d}_T$ and $\mathbf{d}_B$ are the moment arms of the masseter and anterior temporal muscle forces, and bite force from the origin of the coordinate system, respectively (Fig. 1). The sum of the forces acting on the mandible is

$$\sum \mathbf{F} = \mathbf{0} \quad (6)$$

which gives

$$\mathbf{F}_M + \mathbf{F}_T + \mathbf{F}_B + \mathbf{F}_J = \mathbf{0} \quad (7)$$

In the above equation, $\mathbf{F}_J$ is the temporomandibular joint reaction force vector, which can be written as

$$\mathbf{F}_J = F_{JX}\mathbf{i} + F_{JY}\mathbf{j} \quad (8)$$

where $\mathbf{i}$ and $\mathbf{j}$ are the unit base vectors and F_{JX} and F_{JY} are the components of the force along x and y axes, respectively.

The above equations have five unknowns that are the magnitudes of the masseter and anterior temporal muscle forces, bite force, and the two components of the temporomandibular joint reaction force. The magnitude of the bite force is a known input. On the other hand, although the magnitudes of the muscle forces are not directly measurable, the magnitude of one of the muscle force can be expressed in terms of the other if the relative magnitudes of the muscle forces are estimated (27).

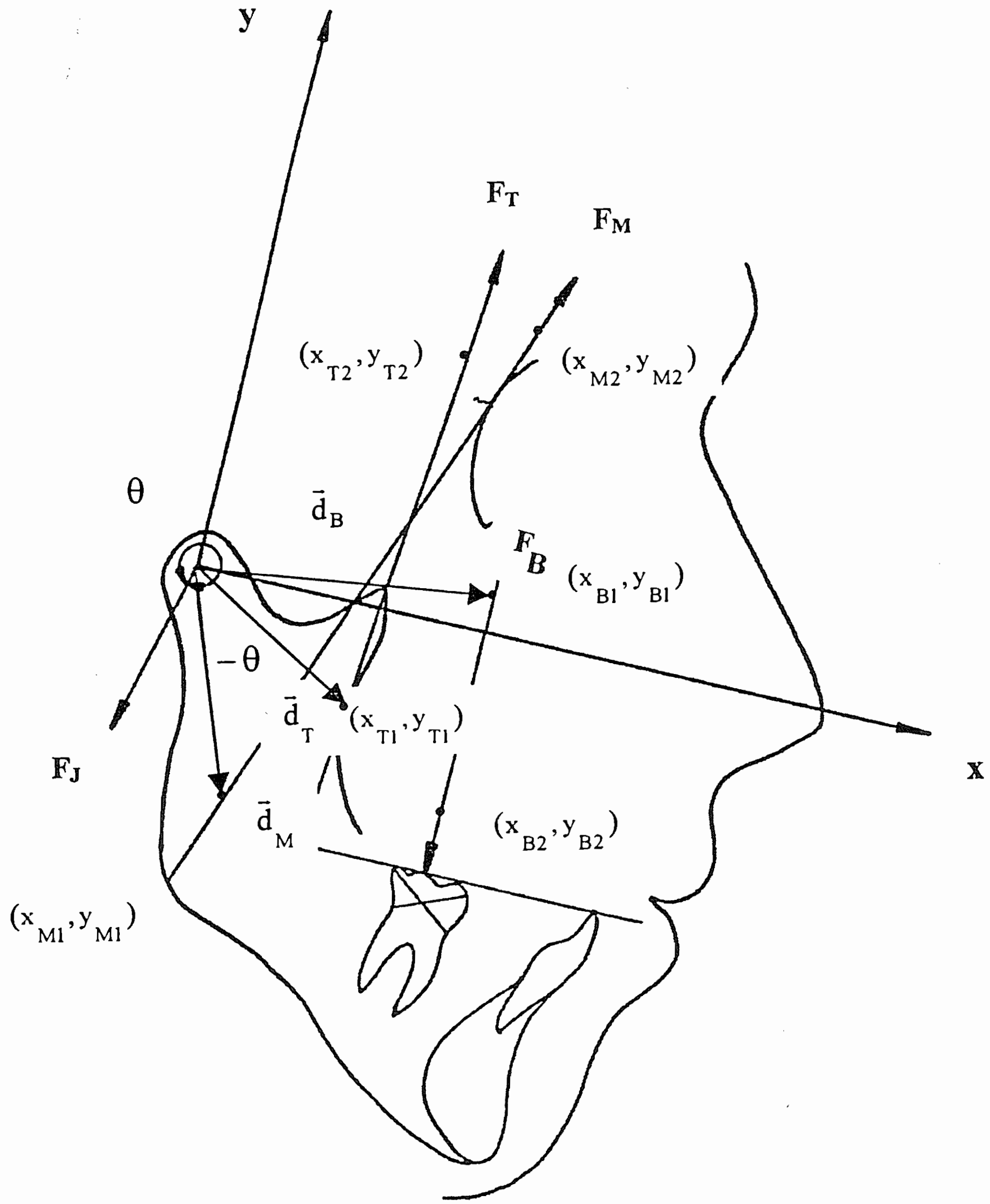

Fig. 1: Two-dimensional model used to calculate magnitude and direction of temporomandibular joint reaction force

Table 1. The skeletal parameters before and after treatment in the activator treatment

Patient	SNA (Deg.)		SNB (Deg.)		ANB (Deg.)		GoGnSN (Deg.)		Gonial Angle (Deg.)		Center of condyle-Pg(mm)	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
1	83	81	76	77	7	4	30	30	110	111	128	127
2	80,5	80	71,5	72,5	9	7,5	34	34,5	98,5	103	124	126,5
3	82,5	83	76	76,5	6,5	6,5	32	26,5	102	106	130	121
4	79	79	74	76,5	5	2,5	27	27	109	111	117,5	129,5
5	75	74,5	68	69	7	5,5	38	37,5	96	103	131,5	131
6	77	79	70,5	74	6,5	5	38,5	37	113	118	134	135
7	83,5	85,5	73,5	77,5	10	7	33,5	31,5	96	106,5	117	120,5
8	82,5	84,5	75	77,5	7,5	5	34	32	106	106	126,5	128,5
9	79,5	78,5	69	71	10,5	7,5	38	38,5	111	107	123	132
10	80,5	79	74	74,5	6,5	4,5	34	34,5	106	105,5	123	117,5
11	77,5	77	72,5	73	5	4	33	35	106	106	125,5	131,5
12	83,5	84	76,5	77,5	7	6,5	33	32	116	116	120	122

$$\frac{F_M}{F_T} = K \quad (9)$$

where K is a constant.

By using Equations (5), (7) and (9), the components of temporomandibular joint reaction force vector can be determined in terms of the magnitude of the bite force and the constant K. Then the magnitude and direction of the temporomandibular joint reaction force can be calculated as follows

$$F_J = \sqrt{F_{JX}^{2} + F_{JY}^{2}} \quad (10)$$

$$\theta = \tan^{-1}\left(\frac{F_{JY}}{F_{JX}}\right) \quad (11)$$

The calculations were undertaken using a computer program based on the mathematical model described.

The relationship between the integrated EMG (IEMG) activity and isometric muscle force has been discussed by many authors and existence of a linear relationship between IEMG activity and isometric muscle force was postulated, when the contractions are at submaximum level (28). In this study, it is assumed that the magnitudes of the muscle forces are proportional to IEMG activity such that

$$F_M \propto A_M IEMG_M \quad (12)$$

$$F_T \propto A_T IEMG_T \quad (13)$$

where A_M and A_T are the physiological cross sectional areas and $IEMG_M$ and $IEMG_T$ are the IEMG activity of the masseter and temporal muscles, respectively.

Then, the ratio of the magnitude of masseter muscle force to the magnitude of anterior temporal muscle force, K, is estimated from the following equation.

$$K = \frac{A_M}{A_T}\frac{IEMG_M}{IEMG_T} \quad (14)$$

The physiological cross sectional areas of masseter and anterior temporal muscles are taken as 340 mm^2 and 240 mm^2 in the study (29). To measure EMG activity surface electrodes with silver discs were used. The records of the subjects were taken using the unipolar method. Recordings from the left and right sides of the anterior temporal and masseter muscle were taken 3 times and the mean value of the all measurements was used. Differences between the recordings taken at the beginning and end of the treatment were tested by the statistical method of paired comparisons. IEMG activity values of masseter and anterior temporal muscles that were recorded before and after treatment for a bite force magnitude of 200 N are used in Equation (14) and calculated K values are given in Table 2. Finally Equations (10) and (11) are used to obtain the magnitude and direction of the temporomandibular joint reaction force.

Table 2. K values determined before and after treatment.

Subject	Before treatment	After treatment
1	1.01	1.23
2	0.98	1.18
3	0.86	0.81
4	1.08	0.88
5	0.87	0.60
6	0.60	1.55
7	0.62	0.81
8	1.11	1.12
9	0.76	0.97
10	0.75	0.67
11	1.49	1.53
12	0.73	0.80

RESULTS

The skeletal parameters of values of the treatment group are given in Table 1. The descriptive values are showed in Table 3. The skeletal parameters SNA, SNB, ANB, GoGn/SN and Gonial angles, and Co-Pg length recorded at the beginning and end of treatment were compared to verify the treatment results. Comparison of the mean changes of the skeletal parameters is given in Table 4. The variation of the SNA, Gonial, GoGn/SN angles and Co-Pg length were found to be statistically insignificant. However the increase in the SNB angle and decrease in the ANB angle were found to be statistically significant (Table 4).

Table 3. The descriptive values of skeletal parameters before and after treatment with an activator group.

	Before		After	
	$\overline{X}$	$S_{\bar{x}}$	$\overline{X}$	$S_{\bar{x}}$
SNA (°)	80.33	0.81	80.41	0.94
SNB (°)	73.04	0.80	74.70	0.82
ANB (°)	7.29	0.50	5.45	0.45
GoGn/SN (°)	33.61	0.97	33.00	1.12
Gonial Angle (°)	125.00	1.54	126.83	1.57
Co-Pg (mm)	105.79	1.89	108.25	1.38

Table 4. The differences in the skeletal parameters before and after treatment with an activator group.

	$\overline{D}$	$S_{\overline{D}}$	p
SNA (°)	-0.08	0.39	0.84
SNB (°)	-1.66	0.35	0.0006***
ANB (°)	1.83	0.29	0.0001***
GoGn/SN (°)	0.91	0.60	0.016
Gonial Angle (°)	-1.83	1.65	0.29
Co-Pg (mm)	-2.45	1.13	0.053

*** $p < 0.001$

The values of the magnitude and direction of temporomandibular joint reaction force are summarized for molar bite before and after treatment for all subjects in Table 5. The mean values, standard error of means of the magnitudes and directions of the temporomandibular joint reaction forces before and after activator treatment are presented in Table 6. The differences in the mean values calculated for magnitude and direction of the temporomandibular joint reaction forces were not found to be statistically significant (Table 6).

Table 5. Variation in the magnitude and direction of temporomandibular joint reaction force before and after the activator treatment.

	Magnitude (N)		Direction (°)	
Subject	Before	After	Before	After
1	104.93	107.05	-139.30	-139.72
2	141.93	131.74	-110.57	-143.65
3	125.89	144.50	-124.45	-107.32
4	186.13	160.90	-102.69	-125.99
5	104.74	119.04	-144.34	-128.29
6	150.61	187.65	-124.53	-125.26
7	115.46	157.14	-111.27	-93.83
8	334.96	326.87	-126.30	-115.71
9	123.73	149.67	-105.59	-115.89
10	104.62	123.01	-116.92	-104.59
11	128.06	131.04	-131.09	-121.87
12	120.74	136.87	-121.98	-121.21

Table 6. The values in temporomandibular joint reaction force before and after activator treatment in molar bite force.

	Before		After		
	$\overline{X}$	$S_{\overline{X}}$	$\overline{X}$	$S_{\overline{X}}$	p
Magnitude (N)	128.60	6.74	140.27	6.22	0.059
Direction (°)	-115.02	10.30	-98.19	21.95	0.519

DISCUSSION

The total change observed clinically in the activator treatment can be attributed to a number of different components including intra-maxiller tooth movement, changes in the inclination of the maxilla and the mandible, and forward displacement of the mandible originating from condylar growth and remodeling of the articular fossa (2-4, 30).

Functional appliance may unload the temporomandibular joint that increases condylar growth. Direct measurement of forces within the temporomandibular joint is difficult and involves invasive techniques that are not applicable to human subjects. On the other hand Brehnan et al. (31) and Boyd et al. (32) directly measured forces at the temporomandibular joint in the monkeys. In human subjects, mathematical methods applied to determine the temporomandibular joint forces are preferable (27-29, 33-36).

In this study the magnitude and direction of the temporomandibular reaction force have been determined by a mathematical method based on vector algebra. The method uses the activities of the masseter and temporal muscles, which were recorded before and after treatment. It was found that the change in the magnitude and direction of the force was not statistically significant. Hence it can be said that the loading pattern is not changed by the treatment. Although there is no study in this subject in the literature, Haskell (13) found that the direction of condylar reaction force varied from a vertical orientation in the hyperdivergent model to oblique in the hypodivergent model. This result supports the conclusion that the loading pattern is not changed by the treatment in the present study since the change in the direction of the temporomandibular reaction force was not found to be statistically significant.

A change in condylar loading after the treatment may result in the condylar growth. An increase in the TMJ reaction force may retart the condylar growth and if TMJ reaction force decreases condylar growth may increase. However in this study TMJ reaction force significantly after the treatment and as a result condylar growth pattern remained unchanged.

CONCLUSION

A mathematical model based on vector algebra is developed which uses two arbitrary points on each line of action of muscle and bite forces, the relative magnitudes of the muscle forces and bite force as input data. The magnitude and direction of temporomandibular joint reaction force, which are determined by using the developed method before and after functional appliance treatment are compared. The change in the magnitude and direction of the temporomandibular joint reaction force was not found statistically significant. Hence it can be concluded that the temporomandibular joint loading is not affected by functional treatment.

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REFERENCES

1. McNamara JA. Neuromuscular and skeletal adaptations to altered function in the orofacial region. Am J Orthod 64:578-606, 1973.
2. McNamara JA, Carlson AS. Quantitative analysis of temporomandibular joint adaptations to protrusive function. Am J Orthod 76:563-611, 1979.
3. Stockli PW, Willert HG. Tissue reactions in the temporomandibular joint resulting from anterior displacement of the mandible in the monkey. Am J Orthod 60:142-155, 1971.
4. Elgoyhen JC, Moyers RE, McNamara JA, Riolo ML. Craniofasial adaptation to protrusive function in young rhesus monkeys. Am J Orthod 62:469-480, 1972.
5. Harris JE. A cepholometric analysis of mandibular growth rate, Am J Orthod 48:161-174, 1962.
6. Korkhaus G. Present orthodontic thought in Germany. Jaw widening with active appliances in cases of mouth breathing. Am J Orthod 46:270-285, 1960.
7. Marschner JF, Harris JE. Mandibular growth and Class II treatment. Angle Orthod 36:89-93, 1966.
8. Björk A. The principle of the Andresen method of orthodontic treatment: a discussion based on

cephalometric x-ray analysis of treated cases. Am J Orthod 37:437-458, 1951.
9. Harvold EP, Vargervik K. Morphogenetic response to activator treatment Am J Orthod 60:478-490, 1971.
10. Wieslander L, Lagerström L. The effect of the activator treatment on Class II malocclusions. Am J Orthod 75:20-26, 1979.
11. Hinton RJ. Jaw protruder muscles and condylar cartilage growth in the rat. Am J Orthod Dentofac Orthop 100:436-442, 1991.
12. Johnston LE. The curious case of the chimerical condyle. In: Graber LW, editor. Orthodontics State of the Art Essence of the Science. St. Louis: Mosby, p. 88-99, 1986.
13. Haskell B, Day M, Tetz J. Computer-aided modeling in the assesment of the biomecanical determinants of diverse skeletal patterns. Am J Orthod 89:363-382, 1986.
14. Birkebaek L, Melsen B, Terp S. A laminagraphic study of the alterations in the temporo-mandibular joint following activator treatment. Eur J Orthod 6:257-266, 1984.
15. Whetten LL, Johnston LE. The control of condylar growth: An experimental evaluation of the role of lateral pterygoid muscle. Am J Orthod 88:181-190, 1985.
16. Navarro M, Delgado E, Monje F. Changes in mandibular rotation after muscular resection. Experimental study in rats. Am J Orthod Dentofac Orthop 108:367-379, 1995.
17. Pirttiniemi P, Kantomaa T. Electrical stimulation of masseter muscles maintains condylar cartilage in long term organ culture. J Dent Res 75:1365-1371, 1996.
18. Gazit D, Ehrlich,J, Kohen Y, Bab I. Effect of occlusal (mechanical) stimulus on bone remodelling in rat mandibular condyle. J Oral Pathol 16:395-398, 1987.
19. Moss ML, Salentijn L. The primary role of functional matrices in facial growth. Am J Orthod 55:566-577, 1969.
20. Moss ML, Salentijn L. The capsular matrix. Am J Orthod 56:474-490, 1969.
21. Johnston LE. Functional appliances: A mortgage on mandibular position. Aust Orthod J 14:154-157, 1996.
22. Kuster R, Ingervall B. The effect of treatment of skeletal open bite with two types of bite-block. Eur J Orthod 14:489-499, 1992.
23. Nielsen IL. Guiding occlusal development with functional appliances. Aust Orthod J 14:133-142, 1996.
24. Stutzmann JJ, Petrovic AG. Role of the lateral pterygoid muscle and menisco-temporomandibular frenum in spontaneous growth of the mandible and in growth stimulated by the postural hyperpropulsor. Am J Orthod Dentofac Orthop 97:381-392, 1990.
25. Kantomaa T, Rönning O. The effect of electrical stimulation of the lateral pterygoid muscle on the growth of the mandible in rat. Proc Finn Dent Soc 78:215-219, 1982.
26. Greulich WW, Pyle S I. Radiographic atlas of skeletal development of the hand and wrist. Stanford University Press, Stanford, California 1959.
27. Throckmorton GS, Throckmorton LS. Quantitative calculations of temporomandibular joint reaction forces - I. The importance of the magnitude of the jaw muscle forces. J Biomech 18.445-452, 1985.
28. Pruim GJ, Bosch JJ, Jongh HJ. Jaw muscle EMG - Activity and static loading of the mandible. J Biomech 11:389-395, 1978.
29. Pruim GJ, Jongh HJ, Bosch JJ. Forces acting on the mandible during bilateral static bite at different bite force levels. J Biomech 13:755-763, 1980.
30. McNamara JA. Functional determinants of craniofacial size and shape. Eur J Orthod 2:131-159, 1980.
31. Brehnan K, Boyd RL, Laskin JL, Gibbs CH, Mahnan PE. Direct measurement of loads at the temporomandibular joint in Macaca arctoides. J Dent Res 60:1820-1824, 1981.
32. Boyd RL, Gibbs CH, Mahnan PE, Richmond AF, Laskin JL. Temporomandibular joint forces measured at the condyle of Macaca arctoides. Am J Orthod Dentofac Orthop 97:472-479, 1990
33. Barbanel JC. The biomechanics of the temporomandibular joint: A theoretical study. J. Biomech 5:251-256, 1972.
34. Hekneby M. The load of the temporomandibular joint: physical calculations and analyses. J Prosthet Dent 31:303-312, 1974.
35. Mansour RM, Reynik RJ. In vivo occlusal forces and moments: I. Forces measured in terminal hinge position and associated moments. J Dent Res 54:114-120, 1975.
36. Throckmorton GS. Quantitative calculations of temporomandibular joint reaction forces. II. The importance of the direction of the jaw muscle forces. J Biomech 18:453-461, 1985.

YAZIŞMA ADRESİ :
Dr. Nilüfer DARENDELİLER
Assistant Professor
Department of Orthodontics
Faculty of Dentistry, Gazi University
82. Sokak, Emek 06510 Ankara, TURKEY