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**EVALUATION OF CHANGES IN TONGUE PRESSURE
BEFORE DURING AND AFTER CRIB APPLIANCE THERAPY
IN OPEN BITE CASES**

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III) Abbreviations and Symbols

- | | |
|-----------------------|-------------------------------|
| 1. et al. | : And friends |
| 2. mm. | : Millimeters |
| 3. ml. | : Mililiters |
| 4. gr/cm ² | : Gram/ centimeter square |
| 5. kg/cm ² | : Kilogram/ centimeter square |
| 6. p | : Probability |
| 7. % | : Percent |
| 8. N/m ² | : Newton/ square meter |
| 9. App. | : Appliance |
| 10. i.e. | : For example |

1. SUMMARY

Tongue pressure changes were evaluated before, during, and after crib appliance therapy, using diaphragm-type pressure transducer in mixed dentition open bite cases.

Study group consisted of 13 patients, and control group consisted of 6 patients. Crib appliance was applied to the patients in study group. Tongue pressures were measured from the upper and lower central incisors, upper first molar and from the crib appliance itself during rest position and swallowing. Measurements were performed before the insertion, at the time of insertion, one week after the insertion, four weeks after the insertion and 3rd, 6th, and 10th months after the insertion and 2 months after the removal of the appliance. Measurements of the control group were performed at the beginning, 10th month, and 12th month.

In study group, therapy resulted in a disturbance in intraoral pressure equilibrium and open bite value showed significant decreases. Resting tongue pressures on upper first molar remained lower than initial values while swallowing pressures showed a gradual decrease during 10-month treatment period, and returned to initial values after the appliance removal. Resting and swallowing pressures on upper central incisor remained lower than initial values. Resting pressure on lower central incisor remained lower than initial values and swallowing pressure remained the same. Resting and swallowing pressures on crib appliance showed significant decreases. In control group, resting and swallowing pressure changes were insignificant.

Changes in tongue pressure at the end of 10-months crib therapy and 2 months follow-up period were insignificant. Resting tongue pressures remained lower than initial values. In addition, measurements performed on the crib appliance confirm tongue adaptation to the new position.

Keywords: Open bite, tongue pressure, pressure transducer, crib appliance, tongue adaptation.

2. ÖZET

AÇIK KAPANIŞ OLGULARINDA ALIŞKANLIK KIRICI APAREY UYGULAMASINDAN ÖNCE, UYGULAMA SIRASINDA VE SONRASINDA DİL BASINCINDA OLUŞAN DEĞİŞİKLİKLERİN DEĞERLENDİRİLMESİ

Dil itimine sahip açık kapanış bozukluğu olan çocuklarda sabit alışkanlık kırıcı uygulanması ile dil basıncında oluşan değişiklikler diyafram tipi basınç ölçer ile değerlendirilmiştir.

Çalışma grubu 13, kontrol grubu 6 kişiden oluşmuştur. Çalışma grubundaki çocuklara alışkanlık kırıcı uygulanmıştır. Dil basınç ölçümleri üst ve alt santral kesiciler, üst 1. azı dişi ve alışkanlık kırıcı apareyin üzerinden istirahat pozisyonu ve yutkunma esnasında yapılmıştır. Ölçümler aparey ağıza uygulanmadan önce, hemen sonra, uygulamayı takiben birinci hafta, 1. ay, 3. ay, 6. ay, 10. ay ve apareyin çıkarılmasını takiben 2. ayda ölçülmüştür. Kontrol grubunun ölçümleri başlangıçta, 10. ve 12. ayda gerçekleştirilmiştir.

Çalışma grubunda ağız içi basınç dengesinde değişimler olmuş ve açık kapanış anlamlı derecede azalmıştır. Üst azı dişinde istirahat dil basınçları başlangıç değerlerinden düşük kalırken, yutkunma basınçları 10 ay boyunca düşüş göstermiş ve 10. ayda apareyin çıkarılmasını takiben başlangıç değerlerine dönmüştür. Üst santral kesici dişte, istirahat ve yutkunma dil basınçları başlangıç değerlerinden düşük kalmıştır. Alt santral kesici dişte istirahat dil basınçları başlangıç değerlerinden düşük kalmış, yutkunma basınçlarında değişim gözlenmemiştir. Alışkanlık kırıcı üzerinden yapılan ölçümlerde ise istirahat ve yutkunma dil basınçlarında anlamlı düşüşler gözlenmiştir. Kontrol grubunda ise istirahat ve yutkunma dil basınçlarındaki değişimler anlamsızdır.

Sabit alışkanlık kırıcıların 10 aylık uygulanması ve 2 aylık takibi sonucunda dilin uyguladığı basınçlardaki değişiklik istatistiksel olarak anlamlı değildir. İstirahat pozisyonundaki dil basınçları ise 12 ay sonunda başlangıç değerlerine dönmemiş; düşük kalmıştır. Aygıt üzerinden yapılan basınç ölçümleri, dilin bu süre içinde alışkanlık kırıcı aygıtlarla oluşan yeni duruma adapte olduğunu göstermektedir.

Anahtar Kelimeler: Açık kapanış, dil basıncı, basınç ölçer, alışkanlık kırıcı, dil adaptasyonu.

3. INTRODUCTION AND AIM

Anterior open bite is one of the most challenging malocclusions to the orthodontists. Malocclusions characterized by anterior open bite and tongue thrust are often difficult to treat and retain. The etiology lies within factors such as unfavorable growth patterns, heredity, digit habits such as thumb and/or finger sucking, retained infantile swallowing habit, enlarged lymphatic tissue, tongue function and tongue posture.

Because of the complex nature, etiology, and dentofacial pattern of open bite malocclusion, treatment strategies may include behavior modification or orthodontic and orthopedic therapy in growing patients.

For the first 6 months of life, an average infant would show a dominant tongue thrusting and visceral swallow, a transitional thrusting, and lateral spread of the tongue during the next year, and a dominant somatic type of swallow, thereafter. In the average child, the nonnutritive sucking habits spontaneously disappear sometime between the sixth and eighteenth months of life. In some children, these habits may be normal for at least another year or so. These activities may be a part of a compensatory or an adaptive mechanism. The habits persisting more than that have the deforming capability on the orofacial skeleton.

It is widely believed that a relation exists between muscle function and dentofacial forms. It is still being discussed whether muscle function affects bone morphology or it adapts to local changes. Thus, it has been an interest for most authors to find out whether tongue thrust is, a cause of anterior open bite or the reverse is true. For years, orthodontists have studied the relationship between the oral cavity, size, posture, and function of the tongue.

While some authors believe that crib appliance is a successful treatment tool and that correcting the tooth positions in open bite cases should cause changes in swallowing patterns, some authors claim the opposite. Besides, most researchers suggest that patients with anterior open bite have tongue tip protrusion during deglutition and that deglutitive tongue movement in patients with anterior open bite is closely related to their skeletal morphology. In order to find out whether deglutitive tongue movement and tongue function after correction of open bite is changing or not, a

study to evaluate the changes in deglutitive tongue movements and tongue functions in open bite patients after correction of open bite is needed. Although several researchers have emphasized the importance of intraoral pressure, and tongue function has been studied by different imaging techniques, tongue pressure has been studied less than the pressure exerted by lip and cheek (15, 41, 63, 68, 85, 91, 99, 100, 129, 130, 139, 149).

As a result, we aimed to investigate and discuss the changes in tongue pressure during rest position and swallowing before and after crib appliance therapy and effects of crib appliance on dentition in growing subjects with anterior open bite and tongue thrusting.

4. LITERATURE REVIEW

4.1. Open Bite Malocclusion

Anterior open bite is defined as the absence of vertical overlap between upper and lower incisors, with the posterior teeth in occlusion (146). Malocclusions characterized by anterior open bite are often difficult to treat successfully. Numerous theories have been proposed for the etiology of open bite such as; heredity, unfavorable growth patterns, digit habits, enlarged lymphatic tissue, tongue function, and tongue posture (64). According to Pae et al. (107), the etiology remains uncertain but Subtelny and Sakuda (146), Ngan and Fields (105) agree that the etiology is multifactorial. Differences in the composition of masticatory musculature (17), resting tongue posture (93, 119), tongue size (157), and functional activities such as digit sucking (120, 146) are thought to be important factors.

The greatest reason of open-bite problems may be attributed to thumb and finger sucking, a retained visceral or infantile swallowing habit, or a combination of both. The infant begins life with a well-developed tongue-thrusting mechanism. This nursing instinct is one of the best developed of all infantile movements. There are no teeth to get in the way, and the dominant posture of the tongue is one in which the center is depressed, the peripheral portions are raised, and the mass is elongated, ready for plunger like action. The instinct is so powerful that the infant usually engages in the suckling act even when there is no nipple present. There is very little in the way of an articular eminence, so the mandible moves forward readily to assist in the nursing act.

At about 5 to 6 months of age, as the incisors begin to erupt, certain proprioceptive impulses come into play and the peripheral portion of the tongue starts to spread laterally. This change in tongue function is a gradual one, and it is called the transitional stage. As the incisors erupt more fully, the peripheral portions of the tongue occupy the space between the remaining edentulous areas of the upper and lower gum pads, and the more mature somatic swallow is the result. The lips close, and the incisors come together momentarily as the tip of the tongue lies behind the incisors during the swallowing act. As the deciduous canines and molars erupt, the peripheral portions of the tongue still overlies the occlusal surfaces during rest, as the mandible is maintained at

postural resting position. Thus, the tongue assists in maintaining the interocclusal space or clearance.

An average infant would show a dominant and exclusive thrusting visceral swallow for the first 6 months of life, a transitional thrusting, and lateral spread of the tongue during the next year, and a dominant somatic type of swallow, with the tongue contained within the dentition, thereafter (49).

However, it is considered normal for children to engage in nonnutritive sucking during infancy. (148) The most common form is thumb or finger sucking since the mouth is the initial avenue of communication with the outside world, and the orofacial musculature is relatively well developed, this nonnutritive sucking apparently gives the infant a feeling of warmth, a sense of satisfaction that is closely linked to the infantile or visceral swallowing mechanism. As other ways of communication with the outside world develop, as other muscle systems mature, and as visual and auditory stimuli become meaningful, the euphoria induced by the oral activity assumes less importance. In the average child, the nonnutritive sucking habits spontaneously disappear sometime between the 6th and 18th months of life. In some children, these habits may be normal for at least another year or so.

The reason for the persistence of the finger-sucking habit may include slow physiologic maturation, inadequate or improper nursing methods, nipple designs which enhance the infantile thrusting and do not allow the development of more mature somatic swallow during the transitional stage. A hereditary Class II, Division 1 type of malocclusion, can also demand more nonnutritive sucking because of the child's inability to thrust the mandible forward sufficiently. Whatever the reason is, the infant begins with a finger habit of sufficient intensity, frequency, and duration to deform the maxillary anterior segment, forcing the teeth labially and allowing the tongue to move further in this direction. Instead of graduating from the infantile visceral thrusting pattern in the transitional stage to the more mature somatic swallow, the tongue continues to thrust forward. A large part of this activity may be a compensatory condition or an adaptive and adjustive mechanism (49).

With constant tongue-thrust, the tongue drops lower in the mouth and no longer approximates the palate most of the time (143). The tongue naturally elongates in shape as it thrusts forward, decreasing its balancing effect on the buccal segments. Equally

important, the lateral peripheral portions no longer overlies the occlusal surfaces of the posterior teeth during postural resting position. Morphologic and functional changes go hand in hand, each augmenting the other. With changes in the tongue, cheek, and lip muscle functions, the net effect is a significant narrowing of the maxillary arch and over eruption of the posterior teeth. The bilateral narrowing of the maxillary arch frequently creates a cross-bite condition. The open-bite is accentuated by this "vicious circle" activity. Unless normal activity can be restored and a mature somatic swallowing habit achieved, the malocclusion may well be perpetuated and aggravated until nature has established a condition of balance with hereditary pattern, basal bone limits, tooth size, contiguous tissue, the functions of mastication, respiration, speech, and posture as well as deglutition, and other as yet unequated factors. From the point of developing malocclusion, it is incorrect to say that the finger-sucking habit caused the malocclusion. It is entirely correct to say that the finger habit was the first assault on the integrity of the dentition and that the adaptive and compensatory activities of the tongue and lip teamed up to provide a much more significant deforming mechanism. Without the original deforming activity by the finger, however, the subsequent lip and tongue action might never have occurred. For this reason, it is considered a good interceptive orthodontic procedure to place an appliance, which eliminates the finger habit before the arch is deformed sufficiently to require homeostatic muscle action during deglutition (49).

Atkinson (10) states that clinical observation regarding improper swallowing habit is made by holding the hand on the chin of the patient while the patient is in act of swallowing. If the jaw is opened during swallowing, it is an indication that the swallowing is done improperly. If the jaw opens during the act of swallowing, the suprahyoid muscles will pull the body of the mandible downward, bending it just anterior to the angle of the jaw, causing tendency for an open bite. Open bites are all typical, body of the mandible bent down just anterior to the angle of the jaw.

Mouth breathing in children is thought to be associated with a low tongue position, a narrow upper arch, increased lower facial height, excessively erupted molars, anterior open bite, and posterior cross bite--all of which may result in aberrant facial growth patterns (138). In order to breathe from the mouth it is necessary to lower the tongue and extend the head. The posterior teeth super-erupt, mandible rotates

downward, and backward, as the tongue does not compensate the pressure from the cheeks, maxilla becomes narrower, and posterior cross bite can occur and as a result, anterior open bite is seen. This type of malocclusion is very similar to the pattern seen in sucking habits and tongue thrust swallow. Katz et al. (74) reported significant association between malocclusion and sucking habits, besides, no association was found between facial morphology and malocclusion.

4.2. Tongue Thrust and Open Bite

The tongue is a very powerful muscular organ, which exerts tremendous pressure at frequent intervals, twenty-four hours a day, during nighttime and daytime. In tongue thrusting habits, a normal sized or overdeveloped tongue is thrust between the upper and lower teeth each time the patient swallows, producing an open bite. The patient may allow the tongue to rest in the open bite space between the acts of deglutition. Tongue thrusting also permits the molars to elongate, which further complicates the problem of correcting open bite cases even if the tongue thrusting habits are corrected (81).

A simple definition of tongue thrust is stated as the forward movement of the tongue tip between the teeth to meet the lower lip in deglutition and in sounds of speech so that the tongue becomes interdental. This does not include the forward tongue posture, which is more important (156). In his study including 478 patients, Straub (142) reported that abnormal swallowing habit turned out to be definitely due to improper bottle-feeding. Improper bottle-feeding includes large nipple, which occupies the place of the tongue during deglutition. As a result, the nipple rests between the tip of the tongue and upper gum pads and lip since, with the large nipple, the palate is covered. However, tongue thrusting may not be an etiologic factor unique to open bite; it is considered a necessary adaptation during abnormal swallowing (97,140). On the other hand, many studies show that tongue thrusting also known as visceral swallowing or infantile swallowing plays a significant role in the etiology of orofacial deformities. In neonates, the tongue is relatively large and located in the forward suckling position for nursing. Tongue lies between the anterior gum pads and helps in creating lip seal. With the eruption of incisors at approximately 6 months, the tongue starts to retract during deglutition. Over a period of 12 to 18 months, as proprioception causes tongue

postural and functional changes, the transitional stage starts. During the 2nd and 4th years of childhood, functionally balanced or mature, somatic swallowing prevails. Visceral swallowing can persist well beyond the 4th year of life, however, is then considered dysfunctional or abnormal because it is, then associated with certain malocclusive characteristics.

The symptoms of a preserved visceral swallowing pattern usually include tongue thrusting during swallowing, forward tongue posture, swallowing without momentary tooth contact, often-excessive buccinator hyperactivity, contraction of perioral muscles such as hyperactive mentalis muscle and orbicularis oris muscle contraction (49,50).

The type of deglutition in which there is excessive circumoral contraction is because there has to be excessive contraction of the labial musculature where the lips are incompetent and the tongue comes forward to complete the oral seal. This tongue thrust swallow can change quite dramatically if the labial segments are brought into good relationship with the orthodontic treatment so that the lower lip can come to seal on the labial surface of upper incisor teeth.

An adaptive tongue behavior, in which the tongue is not only brought forward in functional movement but also postured forward over the lower incisors at rest to seal with the lower lip, is a very important problem (156).

Tulley et al (156) made an epidemiologic survey and found out that; the orthodontists have always recognized the facial pattern found only in 0.6 percent of the child population, as a difficult problem. This pattern is the one in which tongue thrust, and more importantly, tongue posture produces an anterior open bite together with associated skeletal form, which is very resistant to treatment. In addition, they classified the tongue thrust simply into three groups as,

- a) *Tongue-thrusting as a habit*; in which there is a slight open bite and increased overjet with a Class I or Class II relationship. These patients with persistent tongue thrust-habit can be treated easily by putting the labial segment into its correct position.
- b) *Tongue-thrusting which is endogenous or innate*; in which familial pattern displays tongue-thrusting behavior.

- c) *Tongue-thrusting as an adaptive behavior*, in which the majority of problems fall into this category and the resting posture of the tongue is more important than its functional and deglutitive movements.

Brauder and Holt (16) classified tongue thrust according to the resulting deformity rather than etiology, since the determination of etiological factors was difficult in most cases. They grouped tongue thrust as,

Type I – Nondeforming tongue thrust, in which interdigitation of the teeth and the profile were acceptable.

Type II – Deforming tongue thrust; in which either anterior open bite, procumbency of anterior teeth or associated posterior cross bites are seen. As the tongue is thrust forcefully during swallowing, this results in the intrusion or lack of eruption of anterior teeth creating an anterior open bite. If, however, the tongue is directed primarily toward the maxilla, procumbency of maxillary anterior teeth may be the result. On the other hand, if there is a low postural position of the tongue with low tongue thrust habit, a wide mandibular arch form and consequently anterior and posterior cross bites may occur.

Type III– Deforming lateral tongue thrust; in which lateral thrusting of tongue creates intrusion or lack of eruption of posterior teeth creating posterior open bite.

Type IV– Deforming anterior and lateral tongue thrust, in which tongue covers all the occlusal and incisal surfaces of all teeth during swallowing and this situation is usually associated with large tongue in relation to oral cavity.

4.3. Form and Function

It is widely accepted that an interaction exists between muscle function and dentofacial forms. It has long been discussed whether muscle function influences bone morphology or it adapts to local changes in the environment. In addition, it has been an interest for most researchers to find out whether tongue thrusting during deglutition is a cause of anterior open bite or the reverse is true. For years, orthodontists have studied the relationship between the oral cavity and the size, posture and function of the tongue.

Bauder (13), Harvold (57), Proffit (118), and Schwestka-Polly (128) emphasized that the size of the tongue and its dysfunction played an important role in development of malocclusion. On the contrary, Cleall (21), Milne (98), and Subtelny (145) stated

that the tongue adapts to environmental changes. Tulley (156) also suggest that tongue thrust swallowing is an adaptation to open bite which helps in creating an anterior seal, rather than being its cause.

Straub (143) reported that abnormal tongue movement during deglutition might cause anterior open bite with a large mandibular plane angle during growth of mandible. On the other hand Proffit (120) states that during deglutition the force is exerted for a short duration which is not long enough to have an effect on the morphology of anterior open bite.

As for malocclusion and tongue, Fujiki et al (43) reported that tongue tip position is more protrusive during deglutition in anterior open bite. Hanson et al (55) described the deleterious effects of tongue, resulting in over eruption of the posterior teeth, open bite, or overjet. Besides, Cozza et al (24) reported that, prolonged sucking habits and hiperdivergency in the mixed dentition were related with narrow maxillary intermolar and intercanine widths, increased posterior transverse discrepancies, and increased prevalence of posterior crossbites.

To understand the role of tongue in the development of occlusion, Chia-Fen Cheng et al (19) examined the relationship between tongue movements during swallowing and dentofacial morphology with ultrasonography, cephalometric radiography and dental casts in 112 adult volunteers. To imitate habitual swallowing or wet swallowing rather than dry swallowing, all subjects were asked to swallow 3 to 5 ml of water, wait 10 seconds, and then swallow again. The last swallow was recorded and evaluated. They found significant correlations between tongue movement during swallowing and dentofacial morphology.

Fujiki et al (44) made an investigation to find out the relationship between maxillofacial morphology and deglutitive tongue movement in patients with anterior open bite. Ten patients with anterior open bite were the study group and 10 patients with normal overbites were used as the control group. Maxillofacial morphology was measured by cephalometric tracings and deglutitive tongue movement and dorsal tongue function during swallowing were evaluated by cineradiography. The patients with anterior open bite had larger mandibular plane angles, gonial angles and lower face heights than did the controls, indicating skeletal open bites. They found out that those patients had correlations between movement of the dorsal tongue during deglutition and

mandibular plane angle. They suggested that deglutitive tongue movement can produce the maxillofacial morphology, such as open bite with a large mandibular plane angle and on the other hand, the tongue might recognize the dentofacial morphology and modulate its function during deglutition. In patients with anterior open bite, the deglutitive tongue movement might adapt to or compensate for the maxillofacial morphology.

Despite the significant correlations between tongue movements during swallowing and dentofacial morphology, there is no exact conclusion that abnormal swallowing would cause a malocclusion or that abnormal tongue movements are adaptations to malocclusions. The development of occlusion must be considered as a result of the interactions between genetic factors and internal or external environmental factors. In addition to heredity; frequency of swallowing, how often the tongue exerts force on the teeth, the counteraction of these forces by other muscles such as lips, buccinator muscle, the resistance of dentoalveolar structures against forces and resting posture of tongue should be evaluated (5,19).

Arat and Arman (8) reported treating a girl with Class III open bite because of abnormal volume and function of the tongue. This evaluation supports the theory that form follows function. On the other hand, through achieving normal occlusion and balanced facial structure, the malfunctions are reported to be resolved and the treatment outcomes were successfully maintained. This confirms that normal form allows for normal function. These two statements do not contradict each other.

Although the question whether dentofacial form affects tongue function or tongue function affects dentofacial form still remains unsolved, as Frankel and Frankel stated (39) it is impossible to study form without also studying function, and vice versa. Form affects function and function affects form. Treatment modalities should target both fronts.

4.4. Treatment of Open Bite Malocclusion

Orthodontic treatment of open bite before the 1970s consisted mainly of dentoalveolar changes and/or modification of oral habits. While this treatment was appropriate if the problem was due to a dental malrelationship, it was often inadequate for treating open bites, which were due to skeletal imbalance (64).

Anterior open bite is a dentoalveolar component of dentofacial pattern in patients with increased vertical dimension (also called as facial hiperdivergency, dolico-facial, or high angle facial pattern). Significant vertical skeletal imbalances are observed in the anteroposterior and transverse dimensions (121). Because of the complex nature, etiology, and dentofacial pattern of high angle open bite malocclusion, treatment strategies range from behavior modification to orthodontic and orthopedic therapy in growing patients. As intrusion of posterior teeth becomes more difficult with older age, mechanical treatment options are limited in adult patients. Orthognathic surgery is indicated in adult patients with severe open bite and unaesthetic facial proportions. In recent years, correction of open bite by means of skeletal anchorage as an alternative to the orthognathic surgery is described (34, 35, 86). For the treatment of borderline cases, and those individuals who are unwilling to undergo surgery, the search for different treatment modalities continues (4, 23, 29, 106, 146).

Conventional orthodontic treatment has been directed at inhibiting the vertical maxillary growth with headgear, retarding the mandibular growth with chin-cups, or extruding anterior teeth with vertical elastics (45, 92, 125, 162). Some other methods that have been used for treatment and retention of anterior open bite malocclusion include tongue crib therapy (8, 23, 64, 146, 173), posterior magnets (170), and functional appliances (39, 54).

One of the methods available for the treatment of open bite is the multiloop edgewise arch wire technique (MEAW) developed by Kim (77, 78). This technique consists of multiloop gable bend arch wires with vertical elastics in canine regions. The aims of this technique are alignment of maxillary incisors relative to the lip line, correction of the inclination of the occlusal planes and uprighting the axial inclinations of the posterior teeth.

Enacar et al (31) modified Kim's technique by using 0.016x0.022 inch upper accentuated curve and lower reverse curve nickel titanium arch wires instead of multiloop gable bend arch wires with intermaxillary elastics applied in canine regions. They reported that their results were similar to those obtained by Kim's technique.

Küçükkeleş et al (84) carried out a study, which consisted of 17 patients with anterior open bite and high angle skeletal pattern treated with reverse curve nickel titanium wires and intermaxillary elastics in canine regions. Treatment changes obtained

by using NiTi arch wires were similar to those obtained by multiloop edgewise arch wire technique.

Alexander (4) reported treating twenty-one year old adult patient with Class I open bite malocclusion by extraction of upper and lower first premolars together with all third molars and nighttime high pull headgear wear, as the patient refuses surgical approach. He suggests series of tongue exercises should be taught to the patient with tongue thrust in order to prevent long-term relapse. These exercises in the first step include positioning the tongue in the palate to produce a 'click '. The next step is to position the tip of the tongue in the 'click' position and force the tip of the tongue upward so the tongue muscles retrain. The last exercise is 3S's; slurp, squeeze and swallow. The patient is asked to collect the saliva, which is the "slurp", bring the teeth together and activate muscles of closure, "squeeze", and the last step is the tongue in click position, the patient swallows.

Kawakami et al (75) treated siblings with spaced arches. Brother was treated with tongue crib and straight pull headgear and sister was treated by partial glossectomy. They reported that partial glossectomy might be an important treatment option in malocclusion caused by enlarged tongue because it contributes to the stability of occlusion during and after treatment.

Medeiros et al (96) reported treating an adult open bite associated with functional macroglossia by means of orthognathic surgery and partial glossectomy and stated some degree of relapse five years post treatment.

Stuani et al (144) reported treating a 7-year-old girl with atypical deglutition habit and an anterior open bite with a removable vertical crib for a year. As this was not enough for correction due to skeletal origin of the malocclusion, an orthodontic appliance that included an acrylic occlusal splint and an expansion screw, based on the original Thurow appliance with craniomaxillary (high-pull) traction was used.

Graber (49) states that optimal time for appliance placement in children with finger habits is between the ages of 3.5 and 4.5 years. If the occlusion has been sufficiently deformed by the finger habit, if a morphogenetic pattern of incisor protrusion has been aggravated to a degree requiring abnormal lip and tongue function of an adaptive nature, or if there is merely a retained infantile tongue-thrusting habit instead of more mature somatic swallow, a tongue-thrust appliance is used. The crib

appliance serves as rendering the finger habit meaningless by breaking the suction, and the child gets no real satisfaction even if he places his finger in his mouth. The appliance prevents finger pressure from displacing the incisors further labially and creating abnormal tongue and lip function. The appliance also forces the tongue backward, changing its shape during postural resting position from an elongated mass to a wider more nearly normal tongue. As a result, the tongue tends to exert more pressure on the maxillary buccal segments and the narrowing of the maxillary arch by the abnormal swallowing habit is reversed. The peripheral portions of the tongue overlie the occlusal surfaces of the posterior teeth, preventing them from over eruption. The child is encouraged to learn the somatic swallowing habit by crowding back of the tongue and by the change in resting shape.

Huang et al (64) showed that a tongue crib can effectively modify tongue posture, and that it improves stability for growing and nongrowing patients. They reported that they eliminated open bite with a high success rate and the results were maintained throughout the follow-up period.

Yashiro and Takada (173) used a maxillary tongue crib and an edgewise appliance in a 19 year old patient with bimaxillary protrusion. Electromyographic results obtained 2 years after treatment showed significant adaptation of genioglossus muscle activity during swallowing.

Arman and Arat (8) reported treating a severe Class III open bite patient with maxillary tongue crib appliance and chin cup. They claimed that tongue crib and chin cup improved the intermaxillary relationship eliminating patient's negative overjet.

De Cuebas (26) reported using tongue crib with a palatal button for 19 months in an 11-year-old patient showing significant open bite who has tongue-sucking habit with inadequate tongue posture. He stated excellent stability results 3 years posttreatment.

Viazis (159) used triple loop corrector for stopping thumb sucking habit in a 10-year-old girl. He reported that the corrector stopped the habit in one month and the open bite had decreased significantly in 4 months time.

Cozza et al (23) carried out a study on 21 growing patients with thumb sucking and both dental and skeletal open bites with a mean age of 8.4 ± 1.4 years. They used quad helix/crib appliance for the correction of open bite. The mean duration of crib wear was 18 months and dental and skeletal relationships were corrected significantly.

Haryett (58,59) studied the effectiveness of crib appliances in patients with thumb sucking habits and reported that cribs were very effective in stopping the habit when worn for 10 months. Half of his sample was less than 6 years old.

Justus (72) reported that tongue cribs were effective in closing the open bites when worn for one year. He also stated that using cribs with sharp spurs is recommended in open bite cases related to anterior tongue posture.

Subtelny and Sakuda (146) evaluated a sample of eight open bite patients with mean ages greater than 12 years old who wore tongue cribs for 6 months. They reported no closure of open bite during that time.

Epker and Fisch (32) stated that cribs were usually not effective for treating open bites except in growing patients with Class I occlusion, good facial esthetics, and lip competence.

Huang et al (64) carried out a study on stability of anterior open bite treated with crib therapy on 33 open bite patients. The length of crib use varied between 5 to 40 months. The study group consisted of growing and nongrowing patients. They recommended cribs should be worn for at least six months or until the patient achieves positive overbite. They also reported that small number of relapse patients (evaluated a minimum of one year after crib removal) suggested that, the crib improves stability in patients with pretreatment open bite and the reason for this increased stability may be due to a modification of tongue position or posture.

Pedrin et al (108) carried out a study to see the treatment effects of a removable appliance with palatal crib combined with high-pull chin cup therapy in anterior open bite patients. Therapy lasted 12 months and they reported that positive outcomes of the treatment consisted of dentoalveolar changes rather than showing significant changes in maxillary and mandibular skeletal components.

In 2008, Giuntini et al (46) investigated dentoskeletal changes associated with fixed and removable appliances with a crib in mixed dentition open bite patients. The mean duration of treatment was 1.5 years in both groups. Fixed appliance consisted of a quad helix associated with palatal crib (Q-H/C), and removable appliance consisted of a removable plate associated with a jackscrew and a crib (RP-C). They reported that both appliances induced favorable dental effects. However, a compliance-free appliance, such as Q-H/C, produced more favorable skeletal changes.

4.5. Pressure

Pressure in Pascal (Pa) is defined as force (N) per unit area (m^2). In order to define pressure, the standard measurement units used are Pascal, N/m^2 and gr/cm^2 . The meaning of system pressure is the force that the system units apply on system's unit area. The pressure in a system can be measured by using pressure sensors.

4.5.1. Classification of Physiologic Pressures

All pressures fall into one of two classifications, either intentional or unintentional. The intentionals are the planned pressures, and the unintentionals are the abnormal pressure habits. Intentional pressures are applied for specific reasons. Unintentional pressures occur unconsciously and they are of four types: (A) intrinsic pressures within the mouth; (B) extraneous or extrinsic pressures on the face; (C) abnormal pressure habits; and (D) functional pressures (81).

I- Intentional Pressures

- Orthodontic treatment appliances.
- Myofunctional therapy
- Intentional head deformation (ex: giraffe-necks of Padaung women)
- Chinese custom of foot binding
- Reshaping horns of cattle

II- Unintentional Pressures

A- Intrinsic Pressures

- Tongue pressure
- Lip and cheek pressures
- Eruption pressures
- Occlusion pressures
- Postural muscle activities.

B- Extrinsic Pressures on the Face

- Abnormal posture
- Unfavorable habitual sleeping position (habitually sleeping on the right side of the face may cause the nose to turn leftward or vice versa; a deflected septum may also result from this sleeping habit).

- Chin propping
- Face leaning on hand

C- Abnormal Pressure Habits

- Thumb-sucking
- Tongue-sucking
- Lip-sucking
- Cheek-sucking
- Blanket-sucking
- Nail-biting
- Lip-biting
- Tongue-biting
- Tongue-thrusting
- Macroglossia, overgrowth of tongue
- Incorrect swallowing
- Mouth breathing

D- Functional Pressures

- Kyphosis or round shoulders common among dentists, school children, tailors caused by occupational pressures
- Malocclusions frequently developed in musicians from pressure exerted on their teeth or face
- Spinal curvature resulting from abnormal sleeping positions and postural irregularities.

As our study is based upon tongue pressure, only intrinsic pressures will be discussed.

Bone is an ever-changing tissue that is constantly being repaired and replaced from infancy to old age. According to Sicher (131), although bones are permanent structures in our bodies, constant daily repair goes on just like old buildings being restored and scaffolds always can be seen on the sides of these buildings where workmen are replacing defective stones with solid ones so that the structure is in constant repair. Sicher believes that one cannot grow or destroy bone but merely stimulate it. He says that bone never grows under pressure but that cartilage grows under pressure and, in turn is replaced by bone. According to Sir Arthur Keith (76),

osteoblasts at all times build or unbuild according to the stress they are subjected to. On the other hand, Wolff (113) believed that pressure, not tension, is the cause of bone development. The amount of bone growth depends upon the need for it.

Although bone is extremely susceptible to the guidance and influence of pressure and stimulus, the extent to which bone can be changed with pressure or stimulus is controversial. Conservative authorities on bone growth believe that orthodontic treatment (intentional pressure) cannot change basal bone; due to the hereditary factor, the pattern of the basal bone remains the same. However even the most conservative group will agree that alveolar bone can be changed and the teeth in that bone regulated with orthodontic treatment. Pressure habits (unintentional pressures) also change alveolar bone and move teeth in that bone because the bone-building cells on the receiving end of the stimulus cannot differentiate whether the stimulus is intentional (planned orthodontic treatment) or unintentional (abnormal pressure habit).

Occipital and parietal bone of the skull hold the brain case, they are hard and can stand pressure, while face with its cartilaginous bone, yields easily to stimulus and pressure, especially during growth spurts, and presents the most complicated growth problem in the entire skeleton since the greatest growth changes in the head are made by the facial structures. According to Strang (141), the face increases in size about 12 times from birth to adolescence while the cranium increases about 4 times. Since the greatest growth changes in the head are being made by the facial structures, it logically can be assumed that all abnormal pressures should be kept from this vulnerable target, the face. It is during transition from the deciduous to the permanent dentition that much of the damage takes place, and it is during this transition stage that the avoidance of all abnormal pressure habits is of utmost importance. One may argue that, sometimes children with abnormal pressure habits have well developed faces and have no malocclusion, and how can the same habits cause facial abnormalities in other children? According to Fluhrer (38), healthy bone grows and is influenced by environmental factors such as abnormal pressure habits. Bone that has a disturbance in ossification, caused by ill-health, improper diet, or endocrine disturbances resulting in 'bone fatigue' does not grow and consequently is not changed by environmental factors such as abnormal pressure habits, and these cases are exceptions rather than being rule. By the same token, it can be explained why some cases of malocclusion respond to orthodontic

treatment while others with the same malocclusion and receiving the same planned orthodontic treatment do not.

Alfred Paul Rogers (123) stated that structural form is influenced by pressures due to abnormal neuro-muscular activity; the reverse being true that normal pressures, due to function, tend toward normal form in the osseous structures. Klein (81) reached the same conclusion that normal habits maintain normal structural form; abnormal habits maintain abnormal structural form. Therefore, it is logical to attempt to eliminate all abnormal habits, which tend to stimulate and develop alveolar bone into abnormal structural form.

4.6. Tongue, Cheek, and Lip Pressures

Tomes (155) firstly stated the opinion that the position of the teeth on the alveolar bone is determined by surrounding muscles and soft tissues.

In 1899, Edward H. Angle (7) classified the malocclusions and stated that every tooth has a place in the arch and upper and lower arches had a harmony and an occlusion between each other.

In 1904, Wallace (160) reported that tongue might have an influence in helping sustain equilibrium between the forces acting upon the dental arches.

In 1911, E. H. Angle (6) had a new theory about function acting on development. He stated that if the teeth are well aligned and occlusal relationships are good, then there is a normal function. In addition, the stimulation of this normal functioning system leads to an ideal facial development.

S.J. Kloehn (82) carried out a study in 1953 and concluded that there was a force equilibrium to hold the teeth in place in a normal occlusion, and that dental arches were supported by the tongue from inside and by the lips from outside. As a result, a characteristic occlusion for each individual is established.

T.M. Graber (49) in 1963 had a research on muscle forms and their relationships between malocclusions in Class I, Class II and Class III malocclusions. They reported that the effects of muscle forces were not in one direction as opposed, but their effects were three-dimensional. They concluded that when there is a struggle between muscle and bone, bone yields. A change in muscle functions may result in morphologic changes in occlusion or worsen a malocclusion that already exists. As a result, structural

anomaly will continue to increase until equilibrium is established between physiology and morphology.

In 1966, Jacobs and Brodie (70) investigated perioral muscle characteristics during tonic and rest positions and they created an index. According to this index, the average force value for Class II division I was found to be 6.59 gr/cm², for Class III 0.97 gr/cm² and for Class I 0.65 gr/cm².

Next year Jacobs (68) carried out another study and stated that increased index values were directly proportional with excessive overjet and overbite. These values were dramatically affected after repositioning of anterior teeth. The observed decline of IMA scores (Index of Muscular Accommodation) from 7.8 to 1.7 was produced primarily by a significant decrease of maxillary tonic and mandibular contractile forces. In the same manner, relapse of the anterior relationship to its original Class II division I relationship was reflected by recurrence of the characteristic pattern of perimuscular behavior and, correspondingly, large IMA scores.

In 1967, Weinstein (163) disturbed existing pressure equilibrium by placing localized additions on the tooth surfaces and observed tooth movement. As he removed the additions from the surfaces, teeth moved back to their original places. This situation supports balance-of-forces hypothesis.

A.C. Brader (15) carried out a study on dental arch form related with intraoral forces. He explained the relationship between dental arch form and surrounding soft tissue pressure mechanism on mathematical and physical rule basis. He stated that dental arch form is made up of teeth, which assume unique positions along a curve representing equilibrium at all points and surrounded by counterbalancing forces of the tongue and of the circumoral tissues. The tissue forces in the resting state are the primary determinants of arch form morphology in contradiction to the intermittent forces where the muscles are in functioning states. The geometry of the curve of dental arch form is so related with the resting forces of the tongue that; $PR=C$ where P = pressure in gr/cm², R = radius of curvature of the elliptic curve at the pressure site in mm, C = a mathematical constant. Considering the circumoral structures as an elastic envelope, the lips and cheeks exert counterbalancing inward tensions against the teeth according to an equation; $P_i = P_e + T (1/R + 1/R')$ where P_i = internal forces, P_e = external forces, T = tension of elastic envelope, R = radius of curvature in the horizontal

plane, R' = radius of curvature in transverse plane. Horizontal form of the dental arch is modulated by 2 variables as the mathematical constant of the tongue muscle energy (C) and the elastic tension of the lips and cheeks (T). Arch form is stabilized and dental equilibrium is attained wherever $C=T$.

In 1974, Wallen (161) carried out a study on six subjects with normal occlusion and 6 subjects with open bite malocclusion. They measured intraoral pressures on different planes and found out that subjects with normal occlusion revealed more pressure on vertical plane than horizontal plane. They also reported that subjects with open bite revealed approximately equal pressures on every plane, and pressures in open bite subjects on vertical plane were less than subjects with normal occlusion.

In 1978, Mitchell and Williamson (99) measured maximum perioral muscle pressures in North American Blacks and Whites. In the study, 98 blacks and 94 whites were used. These two groups were later divided into 4 groups as 8 year-old girls-boys and 15 year-old girls-boys. Fifteen year-old girls-boys group revealed higher perioral muscular pressures than 8 year-old girls-boys group. On the other hand, boys revealed higher pressures than girls did and differences in pressures between blacks and whites were insignificant.

In 1983, Harradine and Kirchen (56) carried out an EMG study in order to investigate the relationship between perioral muscle pressures and tooth positions. Muscle activity was evaluated on 41 untreated subjects during speech, mastication, swallowing functions and in rest position. Evaluations were also carried out on stone models and x-rays of subjects and lip lengths were measured clinically. Their results revealed that perioral muscle activity was related with lip length and lip position. They reported that in subjects with competent lips, resting lip position effected the tooth positions but on the other hand, functions like speech and swallowing were not effective on tooth positions.

Hinto et al (61) investigated respiratory pressures and their effects and reported that these pressures were not high and effective in subjects with normal respiratory system. Besides, they stated that respiratory pressures increased in mouth breathers and head and tongue posture were altered. Because of this alteration, soft tissue pressures were affected and intraoral equilibrium was disturbed.

Thüer and Ingervall (152) in 1986 evaluated the relationship between lip strength and lip pressure. Eighty-four children (aged 7 to 16 years) with varying types of malocclusion were included in the study. The lip strength was recorded with a dynamometer. The lip pressure was measured on the upper and lower central incisors in the rest position and during chewing and swallowing of crisp bread. The lip pressure measurements were made with an extraoral pressure transducer incorporated in a water-filled system with an intraoral mouthpiece. The muscle activity of the lips was recorded electromyographically. There was no correlation between lip strength and lip pressure. Lip strength was lower in children with Angle Class II, Division 1 malocclusion than in children with Class I malocclusion. The lip pressure on the upper incisors, on the other hand, was higher in Class II, Division 1 than in Class I malocclusion, and was lowest in children with Class II, Division 2 malocclusion. The findings suggest that the pressure from the lips on the teeth is a result of the incisor position.

Haas (52) reported that upper incisors had a tendency to incline lingually after the eruption stage. They suggested that the reason might have been the lip muscle pressures.

Proffit and Phillips (117) carried out a study on lip pressures before and after orthognathic surgery to evaluate the relationship between posttreatment soft-tissue adaptation and incisor stability. After all surgical procedures, physiologic adaptation resulted in the maintenance of pressures during speech and swallowing. When the maxilla was advanced by LeFort I osteotomy, a significant decrease in resting pressure of the upper lip was observed instead of the expected increase and incisor stability did not seem related to soft-tissue influences. When the mandible was advanced by sagittal split osteotomy, resting pressure did not increase as expected, but there was a tendency for incisors to become upright after fixation release, perhaps as a rebound from labial tipping in fixation. When soft tissues were relaxed as the mandible rotated forward following superior repositioning of the maxilla, resting pressures decreased and lower incisors tended to be positioned forward as predicted by equilibrium theory.

In 1989, Kato et al. (73) developed a telemetric method to monitor the active and passive perioral forces exerted on the maxillary dental arch. The force sensor had a diameter of 6 mm, a thickness of 1 mm and was kept in mouth for 6 hours during measurements. The forces on the labial surface of an upper central incisor were 1.5

gm/cm² during rest, 10.9 gm/cm² during swallowing, and 5.0 gm/cm² during speech; the corresponding lingual forces were 4.0 gm/cm², 19.1 gm/cm², and 13.9 gm/cm², respectively. Lingual forces were always higher than labial forces.

In 1989, Lubit et al. (94) carried out a study to evaluate the relationship of maximal perioral muscle pressure and tonic resting pressure using a pneumohydraulic capillary infusion system. The purpose was to evaluate the validity of the assumption that high peak pressures are indicative of high tonic pressures and vice versa. The tonic (resting) and peak (maximum) lip pressures of 100 subjects were evaluated. The results showed no statistically significant relationship between tonic and peak lip pressures.

Soo and Moore (139) investigated intraoral lip pressures in 10 children undergoing lip bumper therapy for 8 months. Semiconductor pressure transducers mounted on Tru-Tain stents in the mandibular midline and left canine areas were used to measure lip pressures with the patient at rest and during five functional exercises. They reported that resting and speaking lip pressures for the midline transducer showed significant increases 1 month after lip bumper placement and then decreased to near or below pretreatment levels, possibly an adaptive response. Left-side resting pressures also showed a gradual decrease. In contrast, left-side speaking pressures showed no significant changes over time. Swallowing pressures were not replicable. They concluded that the results suggest an adaptive response of lip muscles that varies according to the anatomic location.

In 1991, Frohlich et al (42) performed a study to evaluate pressure of the tongue on the teeth in 25 young adults with clinically normal occlusion. Measurements were made on upper and lower central incisors and left first molars. Repeated recordings with an intraoral measuring device connected to an extraoral pressure transducer were made in the rest position and during swallowing and chewing. The majority of the subjects had negative pressures at the upper and lower incisors and at the upper molar in rest position. The pressures on the teeth during swallowing were comparatively great, while pressures during chewing were one-fourth to one-half of the swallowing pressures.

In 1992, Frohlich, Ingervall, and Thüer (41) carried out a similar study in 20 subjects with normal occlusion who had participated in the previous study. Measurements in the rest position, during chewing and swallowing from upper and lower incisors and left first molars were recorded with an extra-oral pressure transducer

incorporated in a fluid-filled system with intra-oral mouthpieces. The median pressures in the rest position were low and negative at the upper incisors. Negative pressures at rest were recorded in a few subjects at all four points of measurement, most frequently at the upper incisors and least frequently at the lower molar. The pressures during swallowing were 2-4 times greater than those during chewing.

In 1993, Fröhlich, Ingervall and Schmocker (40) studied the influence of surgical tongue reduction on pressure from the tongue on the teeth. Measurements were recorded in 21 children and adolescents before surgery, and 6 and 12 months after the operation. Simultaneous measurements were made at the lingual surfaces of the maxillary and mandibular incisors and at the left first molar in the rest position and during swallowing and chewing. At the recording 6 months after surgery, resting pressures at the molars were found to be lower than they had been presurgically. No significant pressures were found for pressures during chewing. At the recordings made 12 months after surgery, none of the pressures differed significantly for the presurgical values. Resting pressures were; however, lower than they had been before surgery.

In 1994, Halazonetis et al. (53) investigated the changes in cheek pressures following rapid maxillary expansion. Expansion appliance was not removed during 3 months lasting measurements from right and left 1st molar teeth before and after expansion. Average cheek pressure on upper molar region before expansion was found to be 3 gr/cm² and this average value increased up to 9 gr/cm² after expansion. Pressure change for every 1 mm expansion was calculated to be 0.6 gr/cm². They reported that soft tissue adaptation was not observed at the end of 3 months retention and the pressures remained approximately the same as the values found after expansion.

In 1996, Shellhart et al. (130) used two different types of pressure transducers in order to evaluate the influence of lip and tongue pressure on tooth position. The average resting pressures registered by the beam transducers were 19.7×10^2 N/m² in midline and 10.9×10^2 N/m² in the right canine area. The pressures registered by the diaphragm transducers were 7.4×10^2 N/m² and 4.5×10^2 N/m² in the right canine area. When the method errors were compared, diaphragm-type transducers were found to have smaller error of the method.

Moawad et al. (100) in 1996, examined lip pressure changes after 1 week of simulated dental arch expansion. Twenty subjects wore a mandibular expansion-

simulating stent full-time for 1 week. Resting pressure was measured in the midline and right canine areas. Midline lip pressure decreased significantly after 1 week, while pressure in the canine area did not change significantly. They concluded that there was an adaptive response that varied according to the anatomic location as suggested before by Soo and Moore (139).

In 1997 Hodge et al. (62), reported that the force exerted on lower molars in patients who had undergone lip bumper therapy was not influenced by the lip thickness or lip height.

In 1997, Ackermann and Proffit (2) reported that the physiologic limits of orthodontic treatment (the ability of the soft tissues to adapt to changes in tooth and jaw positions) are far narrower than anatomic limits of treatment. The tolerances for soft tissue adaptation from equilibrium, periodontal and facial balance standpoints are in the range of 2 to 3 mm for expansion of the mandibular arch.

Balters (12) stated that the most important factor influencing dental arch shape was the pressure equilibrium between tongue and buccinator mechanism. This hypothesis supports functional matrix theory of Moss (104).

In 1999, Thüer et al. (154) investigated the pressures on the maxillary and mandibular posterior teeth from the tongue and cheeks in 24 adults aged 22-29 years. The pressure at two maxillary (buccal and lingual) and two mandibular (buccal and lingual) measuring points, and in palatal vault was recorded simultaneously. Repeated recordings of the pressures at rest, during swallowing and chewing were made. The pressures at rest were similar magnitude (about 2 gr/cm²) at the buccal and lingual sides of the mandibular posterior teeth. The median resting pressure at the maxillary posterior teeth was 2.7 gr/cm² on the buccal side and 1.0 gr/cm² on the lingual side. During chewing and swallowing, the pressures on the lingual side of the teeth were greater than those on the buccal side. At rest, about half of the subjects had a negative pressure at the palatal vault. They concluded that the pressure from the cheeks and tongue established the equilibrium of tooth position.

In 1999, Takahashi et al (149) evaluated the effect of changes in the breathing mode and body position on tongue pressure and searched for respiratory related changes in tongue pressure. The maximum tongue pressure during oral breathing was found to be significantly higher than during nasal breathing in both the upright and supine

positions. Changes in body position significantly affected the maximum tongue pressure during oral breathing. The activity of genioglossus muscle changed significantly with different breathing modes and body positions. They stated that changes in the position of the hyoid bone, produced by the changes in the breathing mode and body position appeared to have a critical role in determining tongue pressure.

In 2002, Lapatki et al (89) investigated the factors influencing lip pressures by measuring pressures from two different points on central incisors. According to the results of their study, lip pressures in Class II division 2 malocclusion cases were greater than subjects with Class I occlusion. They reported that this result was not due to hypertonic lip structure; instead, it was due to high lip line and suggested that in treatment of Class II division 2 cases, upper incisor intrusion was necessary in order to eliminate the effect of lower lip pressure.

In 2002, Cheng et al (19) carried out a study to understand the role of the tongue in the development of occlusion and they examined the relationship between tongue movements during swallowing and dentofacial morphology with ultrasonography. The results revealed that the movements of tongue during swallowing were related to dentofacial morphology. The results also showed that the intermaxillary vertical dimension was significantly and positively correlated with the motion magnitude of the tongue movements. Furthermore, they found out that arch length increased with prolonged duration of swallowing.

Takashashi et al. (150) investigated the effects of tongue position on electromyographic activities of masticatory muscles. They reported that the dynamic position of the tongue should be controlled to maintain normal occlusion.

4.7. Equilibrium Theory and Development of Dental Occlusion

Tomes (155) proposed the concept that the position of the teeth in the dental arches is affected by the surrounding musculature as early as 1873.

Equilibrium theory, as applied in engineering, states that an object subjected to unequal forces will be accelerated and thereby will move to a different position in space. Therefore, if any object is subjected to a set of forces but remains in the same position, those forces must be in balance or equilibrium. From this perspective, the dentition is obviously in equilibrium, since the teeth are subjected to a variety of forces,

but do not move to a new location under usual circumstances. If a tooth is subjected to a continuous force from an orthodontic appliance, it does move. Although the dentition is subjected to very heavy forces during function, small additional forces, if they are maintained for a long enough time, can upset the equilibrium and lead to tooth movement (120, 163).

Teeth are subjected to variety of forces in multiple directions yet remain stable most of the time in dental arch. Balance of forces between perioral musculature and tongue cannot be described as a simple one-to-one relationship. Tongue has been shown to exert greater force on the dentition than the perioral muscles (171). Other factors such as the periodontium and alveolar bone support must be considered in evaluations of muscular balance. The duration of force, because of the biologic response, is more important than its magnitude. During mastication, not only do the teeth move slightly, but also the alveolar bone and basal bone of maxilla and mandible bend and flex. These changes occur in a matter of seconds, and the teeth and jaws are restored to their original positions as quickly as they were displaced (49, 118, 139). In contrast to forces from mastication, light sustained pressures from lips, cheeks and tongue at rest are important determinants of tooth position. Even very light forces are successful in moving teeth, if the force is of long enough duration. The duration threshold seems to be approximately 6 hours in humans. Since the light pressures from lips, cheeks, and tongue at rest are maintained most of the time, tooth position should be affected by these soft tissue pressures. If an injury to the soft tissue of the lip results in scarring and contracture, the incisors will be moved lingually as the lip tightens against them. On the other hand, if restraining pressure by the lip or cheek is removed, the teeth will be moved outward in response to unopposed pressure from the tongue. An enlargement of the tongue from a tumor or other source will result in labial displacement of teeth even though the lips and cheeks are intact, because the equilibrium is altered. It seems unlikely; however, that the intermittent short-duration pressures created when the tongue and lips contact the teeth during swallowing or speaking would have any significant impact on tooth position. As with the masticatory forces, the pressure magnitudes would be great enough to move a tooth, but the duration is inadequate (117,120, 124, 151, 153, 156).

Another possible contributor to the equilibrium could be pressures from external sources, of which various habits and orthodontic appliances would be most prominent. As an example, an orthodontic appliance that creates light pressure on the inside of the dental arch might be used to expand the teeth laterally and anteriorly creating enough space to bring the teeth into alignment. Likewise, a functional appliance, containing buccal shields, retracting the cheeks, decreases the cheek pressure effect on the teeth, and the pressure equilibrium is altered. The same reasoning can be applied to habits; if a habit like thumb sucking created pressure against the teeth for more than the threshold duration; it certainly could move the teeth (120).

This concept also makes it easier to understand how playing a musical instrument might relate to the development of a malocclusion. Wind instruments such as clarinets, trumpets and flutes are played by forcing air into the mouthpiece and through the instrument. The forces acting on the anterior teeth of a person playing a wind instrument are large and may influence tooth position. Likewise, professional violin and viola playing involves asymmetric face, neck and shoulder activity. This posture may influence neck, face, cheek, lip and tongue muscles indirectly and equilibrium may be altered. These alterations may be encountered in most devoted professional musicians playing the instrument for longer durations, whereas no alteration is observed in children playing the instruments for short duration of time (80, 83).

Another possible contributor to the dental equilibrium is the periodontal fiber system, both in the gingival tissues and within the periodontal ligament. This gingival fiber network stretches elastically during orthodontic treatment and tends to pull the teeth back toward their original position. The importance of this force has been demonstrated experimentally in monkeys by extracting a tooth and then making repeated incisions in the gingiva so that the transseptal fiber network is disrupted and tooth movement towards extraction space was eliminated (111). It is often wise to eliminate this force after orthodontic therapy by making gingival incisions and fiberotomy, which cut the stretched transseptal fibers in order to keep the teeth properly aligned. However, in the absence of a space created by extraction or tooth movement, the gingival fiber network apparently has minimal effects on the dental equilibrium.

The periodontal ligament itself can contribute to the forces that make up dental equilibrium by absorbing forces and pressures that apply on alveolar bone and teeth.

Besides, although still not completely understood, it seems clear that periodontal ligament plays a significant role in tooth eruption mechanism (120).

4.7.1. Effects of Equilibrium Mechanism on Skeletal Form

The jaws, particularly the mandible, can be thought of as a core of bone to which functional processes are attached. The functional processes of bone will be altered if the function is lost or changed. As an example, the bone of alveolar process exists only to support the teeth. If a tooth fails to erupt, alveolar bone never forms in the area it would have occupied, and if a tooth is extracted, the alveolus in that region resorbs until finally it completely atrophies. The position of the tooth, not the functional load on it, determines the shape of the alveolar ridge.

The same is true for the muscular processes: the location of muscle attachments is more important in determining bone shape than mechanical loading or their activity. Growth of the muscle determines the position of the attachment and as a result, muscle growth can produce a change in the shape of the jaw (120).

While the general shape and position of the maxilla and mandible are determined genetically, the functional matrices play the primary morphogenetic role as to the final size, shape and position of these skeletal components. (94, 102, 103) both normal and abnormal skeletal and dental relationships are stable when the total interacting forces of the functional matrices are balanced and in a state of equilibrium. These forces include the external perioral pressures, the internal tongue pressure, negative intraoral pressure created during swallowing, and respiratory function that influence the posture of the head, jaws, and tongue (94, 119).

The effect of force duration is not as clear for equilibrium effects on jaws as for the teeth. However, the same principle applies: the magnitude of force is less important than its duration. From the perspective of equilibrium theory, intermittent pressures or forces (i.e. protruding mandible when the teeth come into occlusion, sleeping on stomach) have little if any effect on either the position of the teeth or the size and shape of the jaws. As a function of masticatory forces, density of bone should differ but shape should not. Neither masticatory forces nor soft tissue pressures during swallowing or speaking should have any major influence on tooth position (94, 104, 120).

Major equilibrium influences for the teeth are light but long-lasting pressures from the tongue, lips and cheeks at rest. In addition, elasticity of gingival fibers and metabolic activity within the periodontal ligament are also effective in establishing the equilibrium mechanism. These equilibrium influences would affect the vertical as well as the horizontal position of the teeth (118, 120).

4.8. Pressure Measurement Methods on Soft Tissue

There are three principal methods for investigation of the forces and pressures exerted by muscles and soft tissues on various regions of the skeletal system. These are tissue volume measurements, electromyographic measurements, and electrodynamic measurements including strain gauges. Electromyographic studies to detect the electrical response in muscle were reported as early as 1908 by Dunn, Bennett and McIntyre (30) and numerous studies were published in the literature. Of these methods, strain gauge method was accepted to be more promising and Abrams (1), Jacobs and Brodie (67,69), Winders (166,167), Kydd (88), Proffit et al. (115,116), Gould and Picton (47,48) and Lear and Moorrees (90) are among the investigators who published studies on this subject.

Using the same method, in 1953; Alderisio (3), in 1955; Abrams (1), in 1956 and 1957; Kydd (88) and in 1956 and 1958; Winders (165,166) carried out studies on antagonistic muscle pressures of the tongue and lips. Besides, other work involving strain gauges has been done on plastic and metal denture bases and in 1955; Stromberg (63) published findings on the pressure exerted on the tissues by artificial dentures. In 1960, Schöhl (127) studied the movement of teeth under masticatory stresses.

In 1966, Howland and Brodie (63) used resistance bridge transducer as a method for measurement of exerted pressures by buccinator muscle. The general principle involved the conversion of pressure to an electrical potential. This system was accepted as sensitive method for measurement of pressure changes.

In 1972, Posen (112) introduced a new method for assessing the influence of maximum perioral and tongue forces on the incisor teeth. In his study, he used a Hunter gauge, calibrated to give readings in grams, incorporated into a device called as 'pommeter'. This device was later used again by Mitchell and Williamson (99), Thüer, and Ingervall (152) in their studies and was developed as 'dynamometer'.

In 1974, Wallen (161), measured tongue pressures on the incisor region while swallowing and used a new intraoral pressure transducer, which could be angulated easily to the occlusal plane.

In 1983, Weinstein (164) described the human cheeks as fluid-filled, double elastic membrane systems. They stated that after a certain amount of displacement of the cheeks by the movement of an artificial tooth, a plateau was reached with a constant force over a distance of 0.5-1 mm. The conclusion was that the measurements of the resting pressures had to be made within an area of 0-2 mm from the tooth surface. With greater distances, the pressures would increase rapidly.

In 1985, Thüer, Janson and Ingervall (153) measured the forces from the lips on the teeth in children and evaluated electromyographic lip muscle activity using an extraoral pressure transducer incorporated in a water filled fluid system with an intraoral mouthpiece.

In 1985, Archer and Vig (9) used intraoral pressure transducers based on the design by Proffit (115, 118, 119). Each transducer consisted of two resistance foil. Micro measurement strain gauges were placed on the opposite surfaces of a cantilever beam. The gauges were electrically connected in a Wheatstone bridge, measuring the deflections.

In 1988, Proffit and Phillips (117), studied lip pressures before and after orthognathic surgery. Lip pressures were evaluated by an array of five small cantilever beam strain gauge transducers within a thin plastic carrier placed labially and buccally to upper and lower arches.

In 1989, Kato, Kuroda and Tagawa (73) developed a telemetric method to monitor the active and passive perioral forces exerted on the maxillary dental arch. The force sensor had a diameter of 6 mm, a thickness of 1 mm and was able to measure forces continuously for 6 hours.

A year later, in 1990, Lindeman and Moore (91) carried out a study on measurements of intraoral muscle force with foil strain gauges, load cells, and pressure transducers bonded to a stent and to a lip bumper. The pressure transducer was found to be the superior measuring device with respect to size, sensitivity, thermal compensation, factory uniformity, replicability, and validity. Of the functional exercises used in the study, the pronunciation of the words 'phone', 'mom' and 'church' and the exercise of

swallowing were replicable. They concluded that the lips and cheeks applied fluid pressure on the teeth, so the measurements should be made with pressure and not by force-sensing devices.

The same year, Lubit and Wallach (94) used a pneumohydraulic capillary infusion system in order to evaluate the tonic and peak lip pressures. In the system, catheters continuously infused with water transmitted the resistant pressure of upper lip to pressure transducers. These transducers converted the pressures into electrical signals. Thüer and Ingervall (41, 42, 151, 153) used the same method for measurement of pressure from the tongue on the teeth in young adults and children in 1985, in 1991, in 1992 and 1999 and Fröhlich et al (40) investigated influence of surgical tongue reduction on pressure from the tongue on the teeth using the same extra-oral measuring system.

Again, in 1991, Soo and Moore investigated intraoral lip pressures using an EPL6 flatline pressure transducer mounted on a Tru-Tain stent.

In 1996, Moawad et al (100) carried out a study on evaluation of lip pressure on the teeth by using the same type transducer glued directly onto a stent on two points.

The same year, Shellhart et al (130) used a transducer with beam mechanism and a transducer with diaphragm mechanism for evaluation of lip and tongue pressure on tooth position. Both transducer types produced measurements that were reliable and repeatable. The error was smaller for the diaphragm transducer and it was more precise. A year later in 1997, they used EPL6 flatline transducers in order to evaluate changes in lip pressure over a 6-month period when dental arch expansion was simulated (129).

Again in 1996, Umemori et al (158) developed a pressure-distribution sensor (PDS) for evaluation of lip functions. The PDS was based on the principle of optical-pressure conversion used in sensors of robot arms. They used PDS to evaluate pressure-distribution patterns of long-face subjects with extremely large interlabial distances.

In 1999, Takahashi et al (149), examined tongue pressure on the lingual surface of the mandibular incisors using a PS-A type pressure sensor, incorporated in a lingual flange of custom-made intraoral appliance.

In 2002, Cheng et al (19) investigated the relationship between tongue function during swallowing and dentofacial morphology using computer-aided B+M mode of ultrasonography combines with cushion-scanning technique (CST).

In 2003, Küçükkeleş and Ceylanoğlu (85) evaluated the changes in lip, cheek and tongue pressures after rapid maxillary expansion using an EPL BO diaphragm pressure transducer connected to a digital strain indicator. The pressure transducer was calibrated using a pressure chamber, which had a pressure manometer.

In the same year, Chiba et al (20) evaluated the pressure from the tongue exerted on the loop of transpalatal arch using PS subminiature pressure transducer.

In 2005, Ruan et al (124) studied the muscular forces exerted on the deciduous dentition and the relationship between the muscular forces, sex, and oral function. They used a strain gauge computer-aided measuring device with a transducer thickness of only 0.7 mm. The transducer comprised strain gauges and cantilever beams and was insulated with silicone rubber.

4.8.1. Effect of Head Position on Soft Tissue Pressures

The concept of natural head posture was first introduced by Leonardo da Vinci (1452 – 1519) and Albrecht Dürer (1471-1528) who used scaffoldings of horizontal and vertical lines on drawings of models positioned in “natural pose” in order to permit more accurate artistic and scientific replication of the human head (22).

The concept of natural head position (NHP) was introduced in orthodontics in 1950's by Downs (28), Bjerin (14), and Moorrees & Kean (101), numerous researchers have studied its application and established its advantages. Cooke and Wei (22) described the natural head position as the physiologic position of the head while the subject looks into the reflection of his eyes in a mirror located 200 cm ahead. Natural head posture has been shown to be correlated to craniofacial morphology(133, 135, 136, 137), future growth trends (139), and to respiratory needs (118, 134).

Solow and Talgren (136) stated that the extension of the head resulted in an increase in lower incisor retroclination. They also found positive correlations between mandibular retrusion and extended head position. These findings were supported both in adults and children. Solow and Kreiborg (132) suggested that extended head position resulted in tension on face and neck muscles creating high pressures on teeth and facial skeleton. In the virtue of this opinion they introduced ‘soft tissue stretching hypothesis’.

In 1981, Wood (169) measured anterior lingual, posterior lingual, and labial pressures in the mandibles of Class I subjects. He found no significant effect of head position on labial resting pressures.

In 1985, Archer and Vig (9) evaluated the effects of head position on intraoral pressures in Class I and Class II adults. Intraoral pressures were measured by means of transducers mounted in plastic carriers, in natural head position, with 20 degrees of head extension and 20 degrees of head flexion. In Class I subjects, posterior lingual pressures were consistently different from labial pressures in all head positions. In Class II subjects, posterior lingual pressures were different from labial pressures in flexion and natural head positions, and from anterior lingual pressures in flexion and natural head positions. No increase in labial pressures was found in extended head position in either Class I or Class II subjects. They concluded that the head posture should be considered important in evaluating facial morphology and dental equilibrium since every subject showed pressure changes with the change in head posture.

In 1987 Helsing and L'Estrange (60) studied the changes in upper and lower resting lip pressures following extension and flexion of the head and at changed mode of breathing in a sample of 15 adults with Class I molar relationship. The upper and lower lip pressures during natural head posture had a mean value of 3.91 g/cm^2 and 8.5 g/cm^2 respectively. The mean values of the differences between pressures obtained during natural head posture and during 5° , 10° , and 20° of extension showed a continuously, highly significant increase in pressure. During 5° , 10° , and 20° of flexion, the upper lip pressure continuously decreased with highly significant values. Changes in the lower lip pressure during flexion were difficult to measure because of intense muscle activity. A significant decrease was shown for the difference in upper and lower lip pressures between mouth and nose breathing. A significant increase in pressure was observed with 5° extension of the head during mouth breathing.

Thüer and Ingervall (65) measured soft tissue pressures from upper first molar teeth and alveolar process with the head in extension and natural position in 1988. In the rest position, the pressure on the alveolar process was greater than that on the teeth, and at both locations it was slightly greater with the head extended than in the natural position. They concluded that, pressures on the teeth did not vary noticeably with head

position or among rest, chewing or swallowing; but the pressure on the alveolar process during chewing was greater with the head extended than in the natural position.

In 1999, Takashashi et al. (149) carried out a study on effect of changes in the breathing mode and body position on tongue pressure. They reported that, changes in body position significantly affected the maximum tongue pressure during oral breathing. Changes in the position of the hyoid bone produced by the changes in the breathing mode and in upright and supine body position were found to have a critical role in determining tongue pressure.

In 2007, Jiang et al (71) studied the relationship between registered natural head position (RNHP) and estimated natural head position (ENHP). For RNHP, mirror orientation was used to help to adjust the subject's head position. For ENHP, two approved standard photographs were studied by the researchers before obtaining patient's natural head position. They reported that there was a strong correlation between RNHP and ENHP. The mirror orientation prior to obtaining RNHP and the advance standardization of ENHP were essential for validity and accuracy of NHP as an extracranial reference plane.

5. MATERIALS AND METHOD

5.1. Case Selection Criteria

Twenty-four anterior open bite patients with tongue thrusting were selected among the patients seeking orthodontic treatment at Marmara University Department of Orthodontics. Tongue pressure measurements during swallowing, speech and rest position were performed in the study. Lateral cephalometric and Postero-Anterior cephalometric x-rays were also evaluated.

Eighteen patients were selected as the study group and six patients were selected as the control group.

The research group was established according to the following criteria,

- Ages of the subjects will range between 7-11 (Table 1.),
- Children will be in mixed dentition stage,
- Anterior open bite with tongue thrusting will be present,
- All subjects will have normal growth and development pattern without any genetic or hormonal disorder,
- None of the subjects will have previous orthodontic treatment,
- None of the subjects will have active bad oral habits that may interfere with tongue pressure,
- Skeletally and dentally Class I or Class II pattern will be present,
- The presence and full eruption of upper and lower central incisors and all first molars is required in the mouth and they should be healthy,
- No apparent crowding will be present on dental arches.

Attention was paid to the fact that the patients would not use any medicine, which may affect muscle tonus activity. All the subjects and their families were given information about the project and Marmara University Health Sciences Ethical Committee confirmation report was taken for the research.

Five patients were excluded from the study group due to discontinuity for the measurement appointments.

Measurements of the study group were made before the insertion of crib appliance, at the time of insertion, one week after the insertion, 4 weeks after the insertion and 3rd, 6th, and 10th months after the insertion respectively and 2 months after the removal of the crib appliance. Measurements of the control group were made initially, at the 10th month and 12th month. Tongue pressure was measured from the upper molar, upper central incisor, lower central incisor, and crib appliance during swallowing, rest position, and speech. Measurements on the crib appliance were not performed for the control group.

Tongue pressure measurements were carried out using a pressure transducer (EPL BO diaphragm pressure transducer Entran, Fairfield, NJ) (Figure 1.).

Table 1. Age and sex distribution in study and control group (p>0.05).

Measurement Group		Control Group	p>0.05	
Age	9 years 7 months±	8 years 8 months±	MW: 28	0,334
	1 year 8 months	1 Year 6 months		
Sex	Boys	5 (%38,5)	1 (%16,7)	χ^2 :0,90
	Girls	8 (%61,5)	5 (%83,3)	

5.2. Measurement System

5.2.1. Diaphragm Pressure Transducer

A diaphragm type pressure transducer produced by Entran company was used for pressure measurements (Entran-Sensors and Electronics, Fairfield, NJ, USA). Pressure diaphragm is made of a 3.50 mm width and 1 mm thick round metal measurement plate and 8 mm length epoxy coating covering the connection cables (Figure 1, 2, 3, 4). It's being water resistant makes it possible to work faultlessly in the mouth. Pressure measurement range of the pressure diaphragm is -25+25 PSI (-1757+1757 gr/cm²) and it can work between a temperature range of -40 F and +250 F (-5°+125°C). Error range is decreased to %2 for every 100F with the incorporated temperature equilibrium module. The pressure diaphragm is marketed after being calibrated by the company (Figure 5).

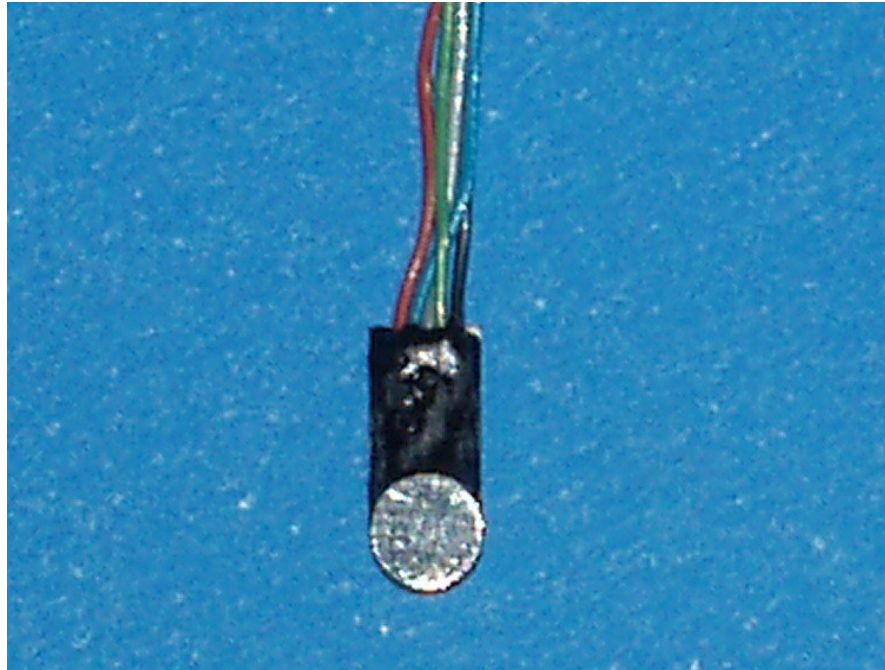


Figure 1. Pressure Transducer



Figure 2. The width of pressure transducer

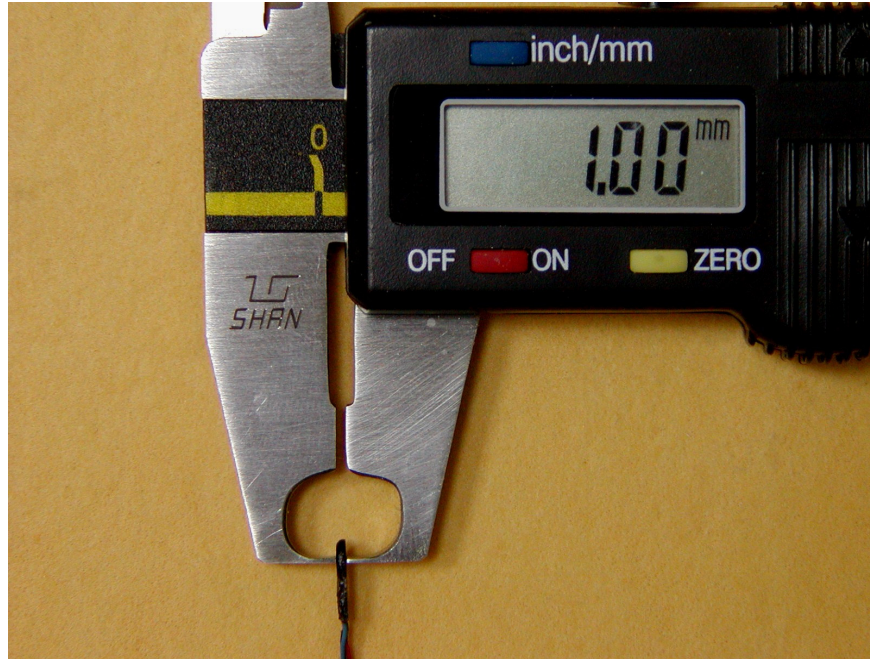


Figure 3. The thickness of pressure transducer

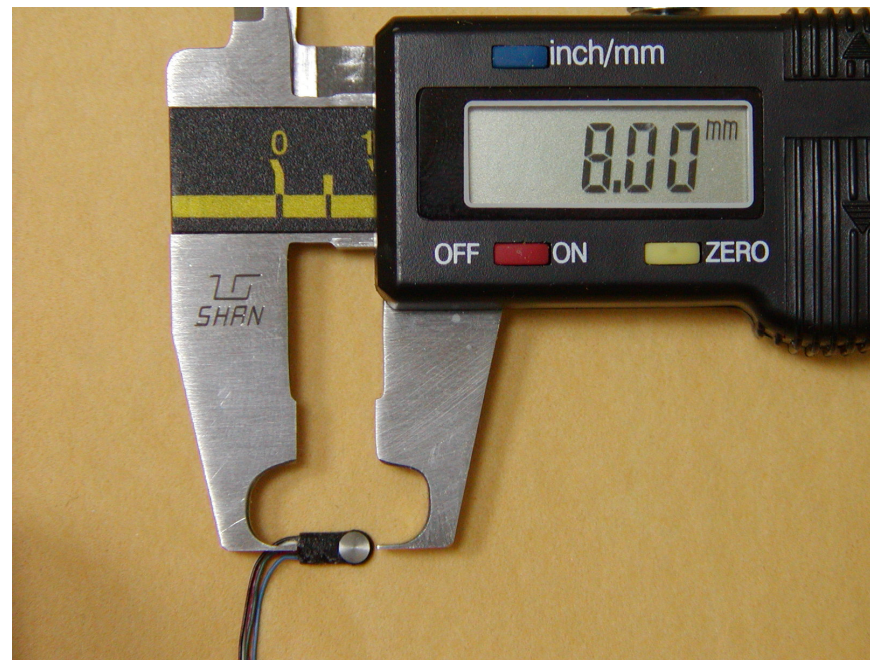


Figure 4. The length of pressure transducer

Entran®

CERTIFICATE OF CALIBRATION

Property of : P.O.# Entran FO#: 42580

PLEASE REVIEW OPERATING SPECIFICATIONS BEFORE POWERING UNIT
CAUTION: DO NOT PRESS OR LOAD THE SENSITIVE AREA WITH A SHARP OR POINTED OBJECT

Model : EPL-B02-25P-/RQ	S/N : 02K01A24-D18
Type : PRESSURE SENSOR	⁴ Mode : N/A
⁴ Range : 25 PSI	Reference : SEALED
Temperature Range	Compensated : 70 TO 170° F
	Do Not Exceed : 75 PSI
	Operating : -40 TO 250° F

NOTE: Exceeding Installation Torque of may damage unit.

CALIBRATION DATA

¹ CNL&H : +/-1%FSO	¹ Hysteresis : N/A	¹ Non-linearity : N/A
¹ Zero :	Thermal Zero Shift: +/-1mV/100° F	² Thermal Sens.Shift: +/-2%/100° F
Ref. Temp : 74° F		² Non-repeatability :
Shunt Cal :	with :	across :
Sensitivity : 64.74 mV/FS	with Excitation : 10 Vdc	Max. Excitation : 12 Vdc
Tested with :		S/N :
Sensitivity :	⁵ with Excitation :	Max. Excitation :
³ Input ohms : 1758	³ Output ohms : 348	
Cal Equip. : DVM US37016661 DWT 69669		
Notes :		

WIRING

Sensor :	Total :
+ In : RED	+ Out: GREEN
- In : BLACK	- Out: WHITE

Figure 5. Certificate of calibration

5.2.2. Strain Indicator

In order to monitor the measurements achieved by pressure transducer, a Measurements Group product P-3500 Strain Indicator was used. (Instruments division, Measurement Groups, INC. Raleigh, North Caroline, USA). This indicator has full bridge, half bridge, and quarter bridge connection types with pressure transducer. In our study, full bridge connection between strain indicator and pressure transducer was used (Figure 6,7).

This strain indicator has a measurement coefficient button, which is adjustable between 0.001 and 9.999 according to the measurement device's resistance coefficient, which is connected to it. P-3500 Strain indicator works accurately between -10 C° and +50C°.



Figure 6. Strain Indicator



Figure 7. Full-bridge connection between strain indicator and pressure transducer

5.2.3. Calibration of Pressure Transducer

Although pressure transducer is already calibrated for the measurement standardization by the producer, we have calibrated it again in order to record the measurements in gr/cm^2 as described below.

A manometer with a measurement range of $-1000 +1000 \text{ gr}/\text{cm}^2$ which has an adjustable airflow property (produced by Endiksan) was mounted on to a pressure pot. The air exit valve of pressure pot was plugged with a hard rubber and air exit from the pot was prevented permitting a passage for the cables of pressure transducer. Pressure transducer was placed in the pressure pot in a way that cables pass through hard rubber and transducer is suspended in the air. Pressure transducer circuits were connected to the strain indicator with full bridge connection. Then, pressure pot cover was closed and air was sent gradually into the pressure pot through the manometer valve with the help of an air source. Meanwhile, the pressure value measured by the pressure transducer in the pot was monitored by strain indicator, and the transducer was recalibrated by adjusting the coefficient of strain indicator until 0001 unit was equal to $1\text{gr}/\text{cm}^2$ ($0.001 \text{ kg}/\text{cm}^2$) (Figure 8, 9).

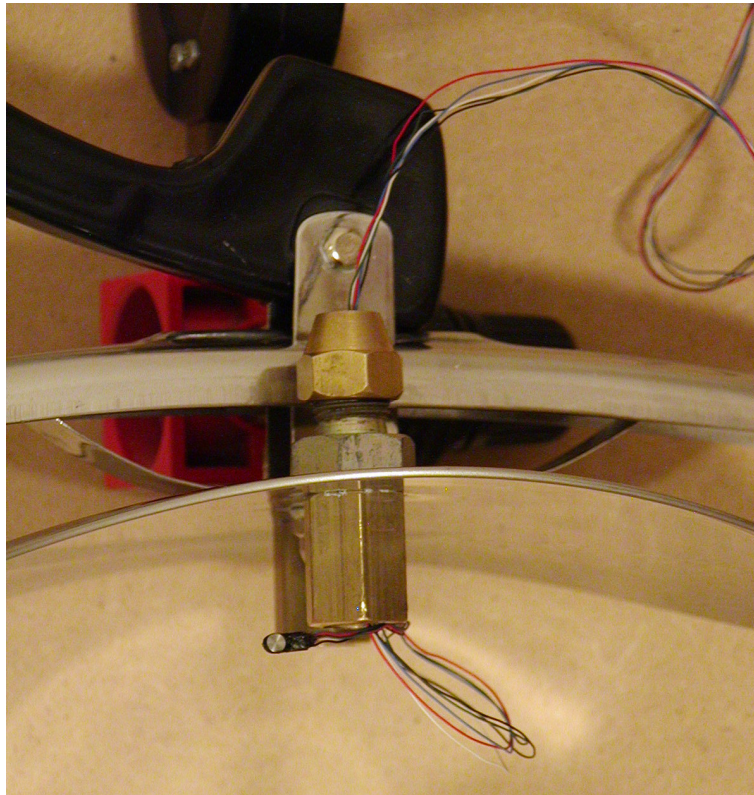


Figure 8. Pressure transducer passing through hard rubber



Figure 9. Calibration procedure

5.3. Patient Records

At the first appointment (before the insertion of crib appliance), intraoral and extraoral photographs, upper and lower jaw impressions, panoramic, lateral cephalometric and Postero-anterior cephalometric x-rays of all patients were taken. Postero-anterior cephalometric x-rays were taken with special acrylic caps designed for all permanent first molar teeth. In the design of caps, 0.7 mm stainless steel wire was bent on the occlusal and buccal surfaces of all permanent first molars and the wire was then covered with orthodontic acrylic on the occlusal surfaces of the molars. After the removal of the crib appliance which corresponds to the 10th month, extra oral and intraoral photographs, Postero-anterior cephalograms with acrylic caps on the molars, lateral cephalometric and panoramic x-rays were taken again from both control and study group.

5.4. Crib Appliance

At the second appointment, after choosing appropriate bands for the upper first molars of each patient, lingual cleats were welded to the bands produced by GAC

company (Figure 10.a). After adjusting the bands in the mouth, the upper jaw impression was taken and the stone model was produced with the bands. On the stone model, the crib appliance was bent using 0.8 mm stainless steel wire with the arms passing through the cleats on the molars. The end part of the crib appliance was tied to the cleat in order to fix it in the mouth. We modified the middle spur of the crib appliance to fit to the dimensions of the pressure sensor of the pressure transducer for the measurements. We also modified the arms of the crib appliance just mesial to the cleat according to the dimensions of the pressure sensor (Figure 10.b).

5.5. Acrylic Carrier Construction

On stone models of each patient, acrylic measurement crowns (carriers) were prepared. Carriers were bent for the diaphragm of the pressure transducer to the lingual surfaces of upper and lower central incisors using 0.7 mm stainless steel wire. In addition, carriers were bent for the diaphragm of the pressure transducer to the upper right first molar band cleat using 0.7 mm stainless steel wire. Attention was paid while bending the carriers to be appropriate for the dimensions of the diaphragm of pressure transducer and in contact with the palatal and lingual mucosa. Fixing the carriers on the stone models, acrylic crowns were prepared on the labial surfaces of upper and lower central incisors (Figure 11.a, b, d, e).

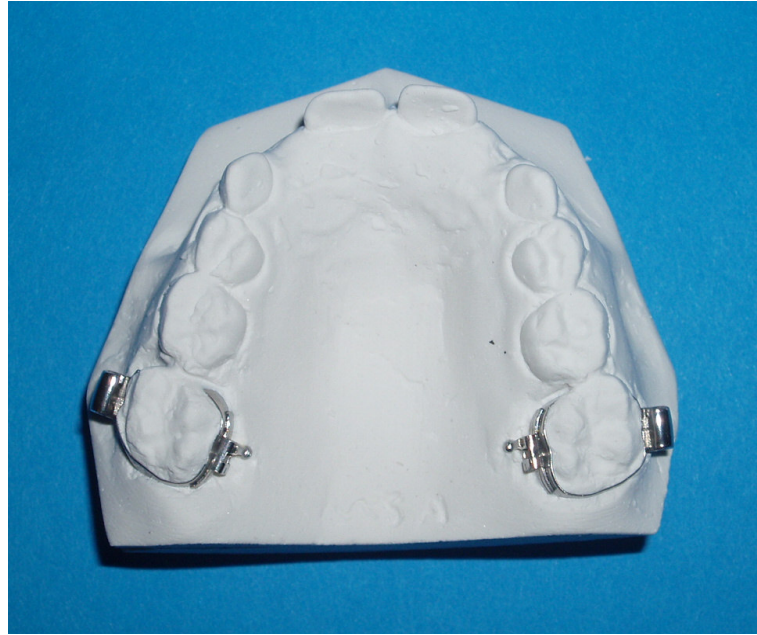


Figure 10.a. Adjusted bands and cleats on upper first molar teeth



Figure 10.b. Crib appliance inserted into the cleats

5.6. Pressure Measurements

5.6.1. Measurements of the Study Group

Pressure measurements of the study group were made from the upper first molar, upper central incisor and, lower central incisor, before the insertion of the crib appliance, during rest position and, swallowing 10 ml. of water.

During measurements, attention was paid to align patient's head in natural head position. To achieve this, dental chair was set upright and the patient's Frankfurt horizontal plane was positioned parallel to the floor. Initially, the carrier was fixed to the upper right first molar and ligated the pressure diaphragm to the upper right first molar carrier parallel to the long axis of molar. After zeroing the indicator, we waited 5 minutes for the pressure diaphragm to reach mouth temperature. Then patient was told to open his/her mouth wide and after zeroing the screen again, patient was told to count until 20 so that he/she could reach rest position at the end and the next 5 values on the screen as rest position were recorded. Secondly, patient was told to open his/her mouth wide again and after achieving zero on the screen, 10 ml. of water was given with a scale to swallow. This was repeated 5 times one after the other and highest values were recorded. Then, the acrylic crown was fixed to lower central incisor and the pressure diaphragm was ligated to the lingual carrier of acrylic crown. Measurement values in rest position and during swallowing were recorded the same way. After that, the acrylic crown was fixed to upper central incisor and the pressure diaphragm was ligated to the lingual carrier of the acrylic crown. Measurement values in rest position and during swallowing were recorded following the same procedure. Additionally, measurements on upper central incisor was performed again during pronunciation of the Turkish words 'pasta', 'çiçek', 'dede' and 'katı'. Zeroing the screen, patient was told to pronounce each word 5 times and the values were recorded (Figure 11.c, f, g, 12. a, b, c, d, g).

At the same appointment, the crib appliance was inserted in the mouth and was fixed to the cleat of upper first molar band. Pressure diaphragm was ligated to the upper right molar carrier of the crib appliance. Measurements were performed following the same procedure in rest position and during swallowing 10 ml. of water. Then, the pressure diaphragm was ligated to the middle spur of the crib appliance and the measurements were made again in the same way in rest position and during swallowing 10 ml. of water (Figure 11.h, i, 12. e, f, h).

After the initial measurements, without removing the crib appliance, the measurements were performed on the upper right first molar carrier of the crib appliance and crib appliance's spur during rest position and swallowing 10 ml. of water in the 1st week of insertion, 1st month, 3rd month, 6th month and 10th month respectively. At the 10th month, crib appliance therapy was finished and the appliance was removed. Measurements were made from the upper central incisor, lower central incisor, and upper right first molar during rest position and swallowing 10 ml. of water with the help of acrylic crowns and carriers as done before the insertion of the crib appliance with the same method. Measurements were made from the upper central incisor again during pronunciation of the Turkish words 'pasta', 'çiçek', 'dede' and 'katı'.

Two months after the removal of the crib appliance (12th month), measurements were repeated from the upper central incisor, lower central incisor, and upper right first molar during rest position and swallowing 10 ml. of water. Measurements were repeated with the same method from the upper central incisor during pronunciation of the Turkish words 'pasta', 'çiçek', 'dede' and 'katı' as done before the insertion of the crib appliance.

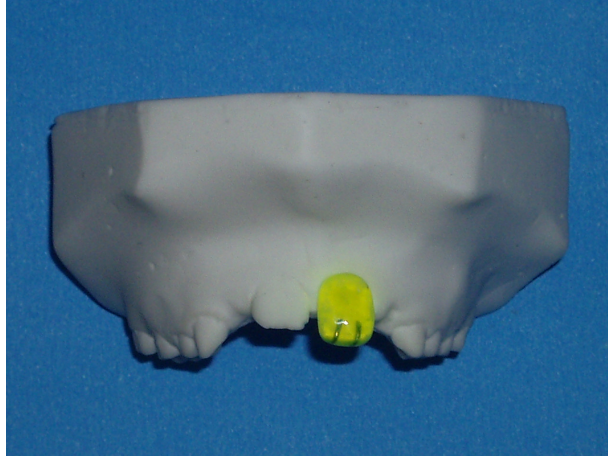


Figure 11 a. Acrylic carrier for upper central incisor, labial view

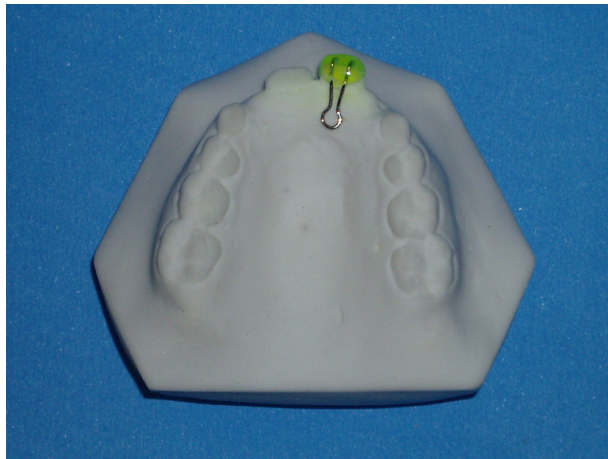


Figure 11.b. Acrylic carrier for upper central incisor, palatal view

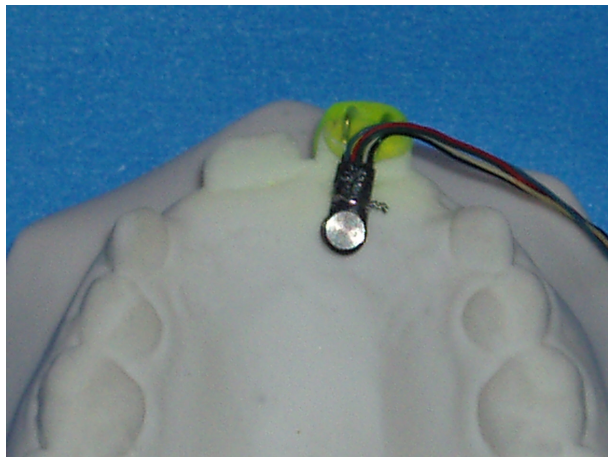


Figure 11.c. Engagement of pressure transducer to the carrier

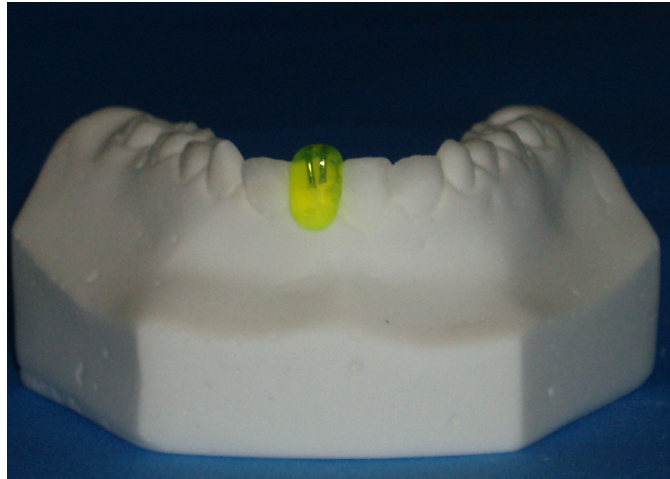


Figure 11.d. Acrylic carrier for lower incisor, labial view



Figure 11.e. Acrylic carrier for lower incisor, lingual view

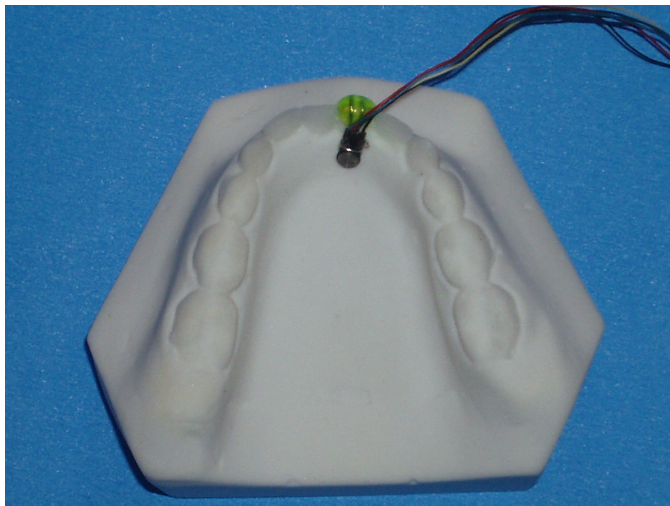


Figure 11.f. Engagement of pressure transducer to the carrier



Figure 11.g. Measurement from the upper first molar



Figure 11.h. Measurement from the crib appliance's middle spur

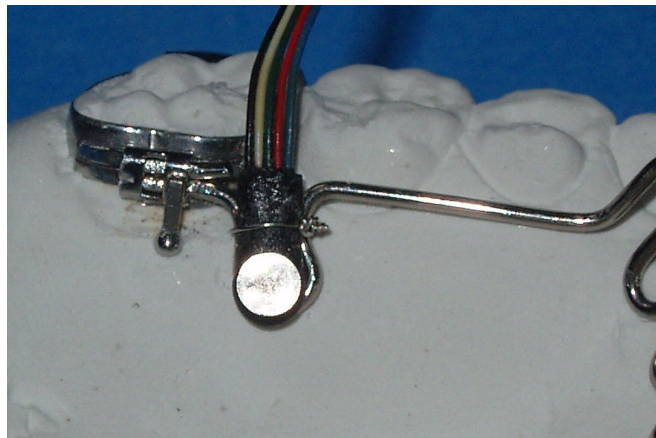


Figure 11.i. Measurement from the upper first molar with the crib appliance inserted

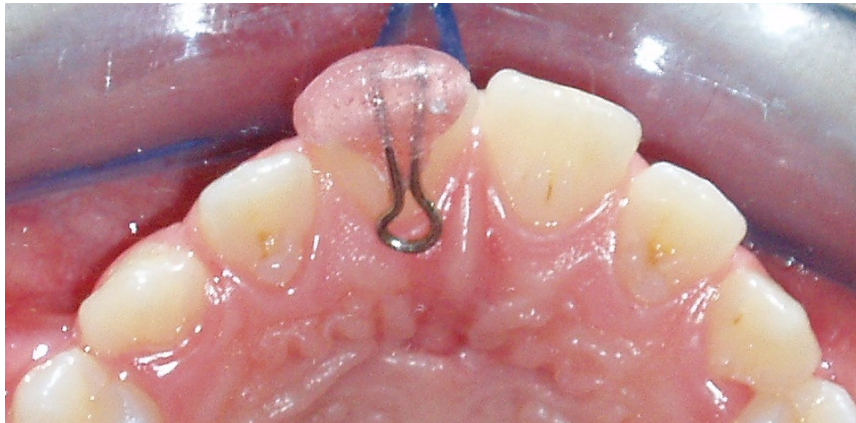


Figure 12 a. Acrylic carrier for upper central incisor

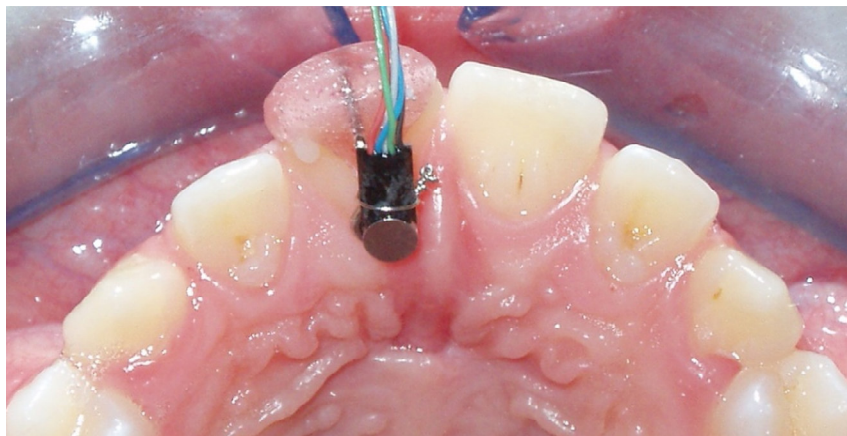


Figure 12 b. Pressure measurement from the upper central incisor

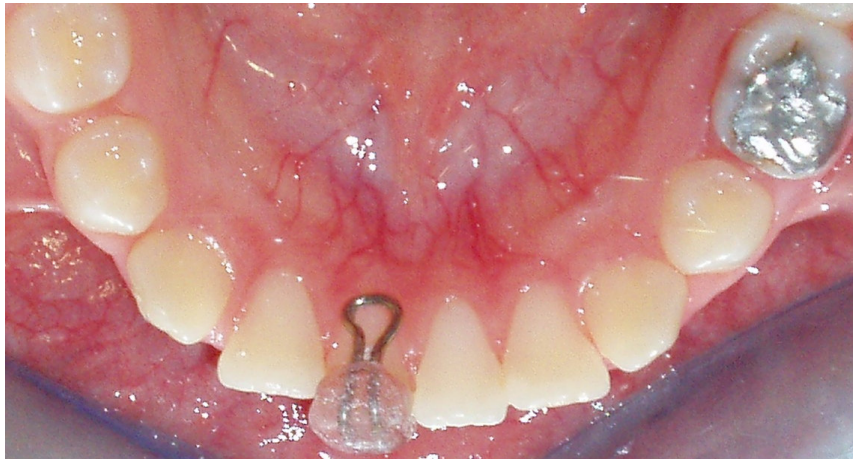


Figure 12 c. Acrylic carrier for lower central incisor

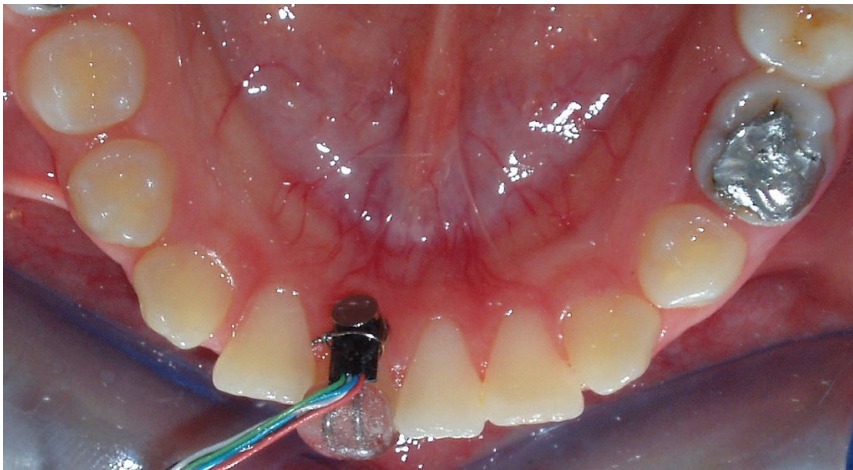


Figure 12 d. Pressure measurement from lower central incisor



Figure 12 e. Subject with open bite

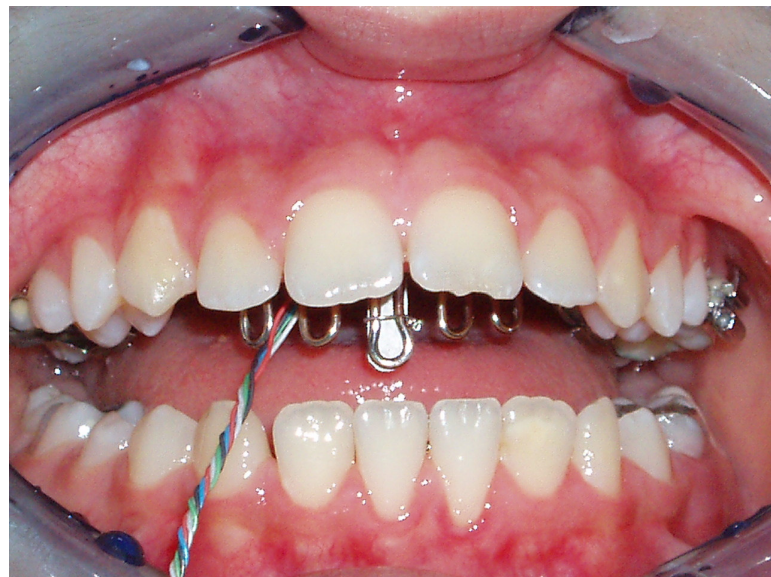


Figure 12 f. Measurement from the crib appliance's middle spur

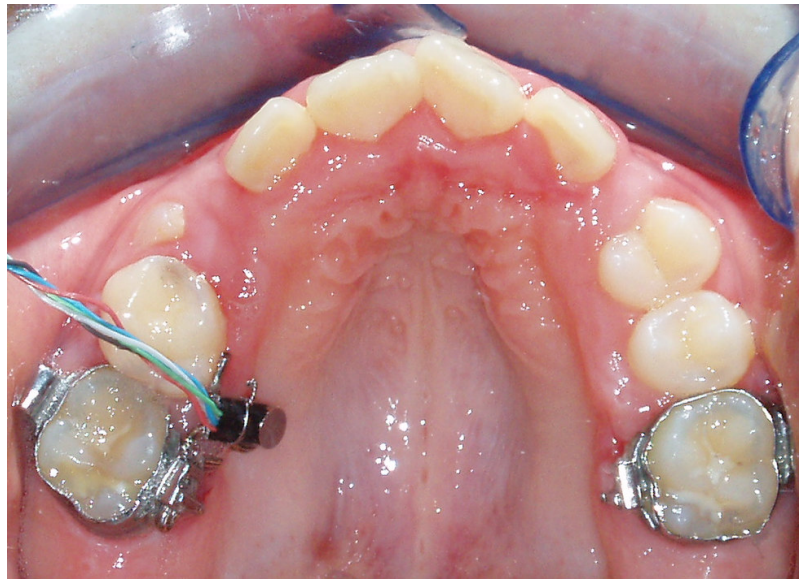


Figure 12 g. Measurement from upper first molar

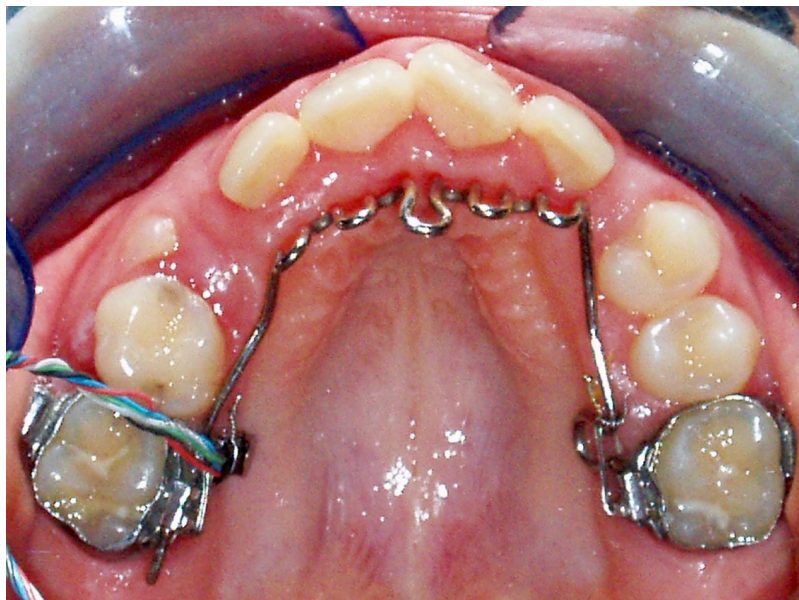


Figure 12 h. Measurement from upper first molar, with the crib appliance inserted

5.6.2. Measurements of the control group

Measurements of the control group were performed on the upper central incisor, lower central incisor, and upper right first molar similarly. Acrylic crown carriers for upper and lower central incisors and upper right molar band carrier were prepared for each patient and the measurements were performed during rest position and swallowing 10 ml. of water at the first appointment, 10th month and 12th month respectively using the same method as achieved in the study group. Measurements were made from the upper central incisor during pronunciation of the Turkish words ‘pasta’, ‘dede’, ‘çiçek’ and ‘katı’ with the same method as study group.

5.7. Cephalometric Evaluation

All the cephalometric x-rays were taken by the same machine. The cephalometric evaluation form present in Marmara University Faculty of Dentistry Department of Orthodontics was used in order to evaluate cephalometric tracings. The cephalometric points, planes, angles, and ratios used in the study are listed below.

5.7.1. Machines Used in Cephalometrics

Lateral and postero-anterior cephalometric x-rays were taken in Marmara University Faculty of Dentistry Oral Diagnosis and Radiology Department. Morita Veraviewapocs machine was used. The distance between the x-ray source and subjects’ ortho-axial plane was 180 cm and the distance between the x-ray film and subjects’ ortho-axial plane was 12 cm. The subjects were posed for 1,2 seconds for lateral cephalometric x- rays, and 1,3 seconds for postero-anterior cephalometric x-rays.

In order to reduce the method error, x-rays were traced by the same observer, and double images were centered while tracing.

5.7.2. Landmarks Used in Lateral Cephalometric X-rays

1- (S): Sella; the centre of hypophyseal fossa (sella turcica).

2- (N): Nasion; the fronto-nasal suture at its most superior point on the curve at the bridge of the nose.

3- ANS: Anterior nasal spine; the most anterior point on the maxilla at the level of the palate.

4- PNS: Posterior nasal spine; the most posterior point on the bony hard palate in the sagittal plane.

5- (A): A point; subspinale; the most posterior point of the curve between ANS and supradentale.

6- (B): B point; supramentale; the most posterior point of the bony curvature of the mandible below infradentale and above pogonion.

7- (Me): Menton; the lowest point on the symphyseal outline of the chin.

8- (Go): Gonion; the most posterior inferior point at the angle of the mandible.

9- (UIT): Upper incisor tip; the incisal tip of the most anterior maxillary central incisor.

10- (LIT): Lower incisor tip; the incisal tip of the most anterior mandibular incisor.

11- (UIA): Upper incisor apex.

12- (LIA): Lower incisor apex.

13- (UMT): Mesiobuccal cusp tip of maxillary first molar.

14- (LMT): Mesiobuccal cusp tip of mandibular first molar (Figure 13).

5.7.3. Planes Used in Cephalometric X-rays

15- SN: Sella-Nasion plane, line passing through S and N points.

16- X axis: (CFH); constructed Frankfort horizontal plane; an artificial horizontal reference plane starting from S point, displaying 7° angle under SN plane.

17- Y axis: An artificial reference plane drawn perpendicular to X axis.

18- MP: Mandibular plane, line passing through Go and Me points.

19- PP: Palatal plane, line passing through ANS and PNS points (Figure 14).

5.7.4. Angular Measurements Used in Lateral Cephalometric Analysis

20-SNA: Antero-posterior position of maxilla to cranial base.

21-SNB: Antero-posterior position of mandible to cranial base.

22-ANB: Antero-posterior relationship between maxilla and mandible.

23-SN-MP: Cranial base to mandibular plane angle (Go-Me).

24- SN-PP: Cranial base to palatal plane angle.

25- U1- PP: Angle of maxillary incisor to palatal plane.

26- U1-SN: Angle of maxillary incisor to cranial base.

27- IMPA: Angle of mandibular incisor to mandibular plane.

28- IIA: Inter-incisal angle.

29- NLA: Naso-labial angle (Figure 15).

5.7.5. Linear Measurements Used in Cephalometric X-rays

30- OB: Overbite; the vertical distance between upper and lower incisor tips' projection perpendicular to Y axis.

31- OJ: Overjet; the horizontal distance between upper and lower incisor tips' projection perpendicular to X axis.

32- UIT-X axis: Distance from upper incisor edge to X axis, perpendicular to X axis.

33-UIT-PP: Distance from upper incisor edge to palatal plane perpendicular to palatal plane.

34-LIT-X axis: Distance from lower incisor edge to X axis perpendicular to X axis.

35-LIT-MP: Distance from lower incisor edge to mandibular plane perpendicular to mandibular plane.

36- UMT-PP: Distance from maxillary first molar tip to palatal plane perpendicular to palatal plane.

37- UMT-X axis: Distance from maxillary first molar tip to X axis perpendicular to X axis.

38- UMT-Y axis: Distance from maxillary first molar tip to Y axis perpendicular to Y axis.

39- LMT-GoMe: Distance from mandibular molar tip to mandibular plane perpendicular to mandibular plane.

40- LMT-X axis: Distance from mandibular molar tip to X axis perpendicular to X axis.

41- LMT-Y axis: Distance from mandibular molar tip to Y axis perpendicular to Y axis.

42- ANS-Me: Lower face height perpendicular to X axis.

43- N-Me: Anterior face height perpendicular to X axis.

44- ANSMe / NMe: Ratio between lower face height and anterior face height.

45- S-Go: Posterior face height.

46- S-Go / NMe: Ratio between posterior face height and anterior face height (Figure 16.1., 16.2.).

5.7.6. Landmarks Used in Postero-anterior Cephalometric X-rays

47- (Lo): Latero-orbitale; the point where orbital contour meets the oblique orbital line.

48- ULM: Upper left molar.

49- URM: Upper right molar.

50- LLM: Lower left molar.

51- LRM: Lower right molar (Figure 17).

5.7.7. Planes Used in Postero-anterior Cephalometric X-rays

52- LOP: Latero-orbital plane (Figure 17).

5.7.8. Linear Measurements Used in Postero-anterior Cephalometric X-rays

53- Upper intermolar width (UIMW): The distance between right and left upper first molars.

54- Lower intermolar width (LIMW): The distance between right and left lower first molars (Figure 18).

5.7.9. Angular Measurements used in Postero-anterior Cephalometric X-rays

55- Upper right molar angulation (URMA): The inner angle between right molar pin axis and the latero-orbital plane.

56- Upper left molar angulation (ULMA): The inner angle between left molar pin axis and the latero-orbital plane.

57- Lower left molar angulation (LLMA): The inner angle between lower left molar pin axis and latero-orbital plane.

58- Lower right molar angulation (LRMA): The inner angle between lower right molar pin axis and latero-orbital plane (Figure 18).

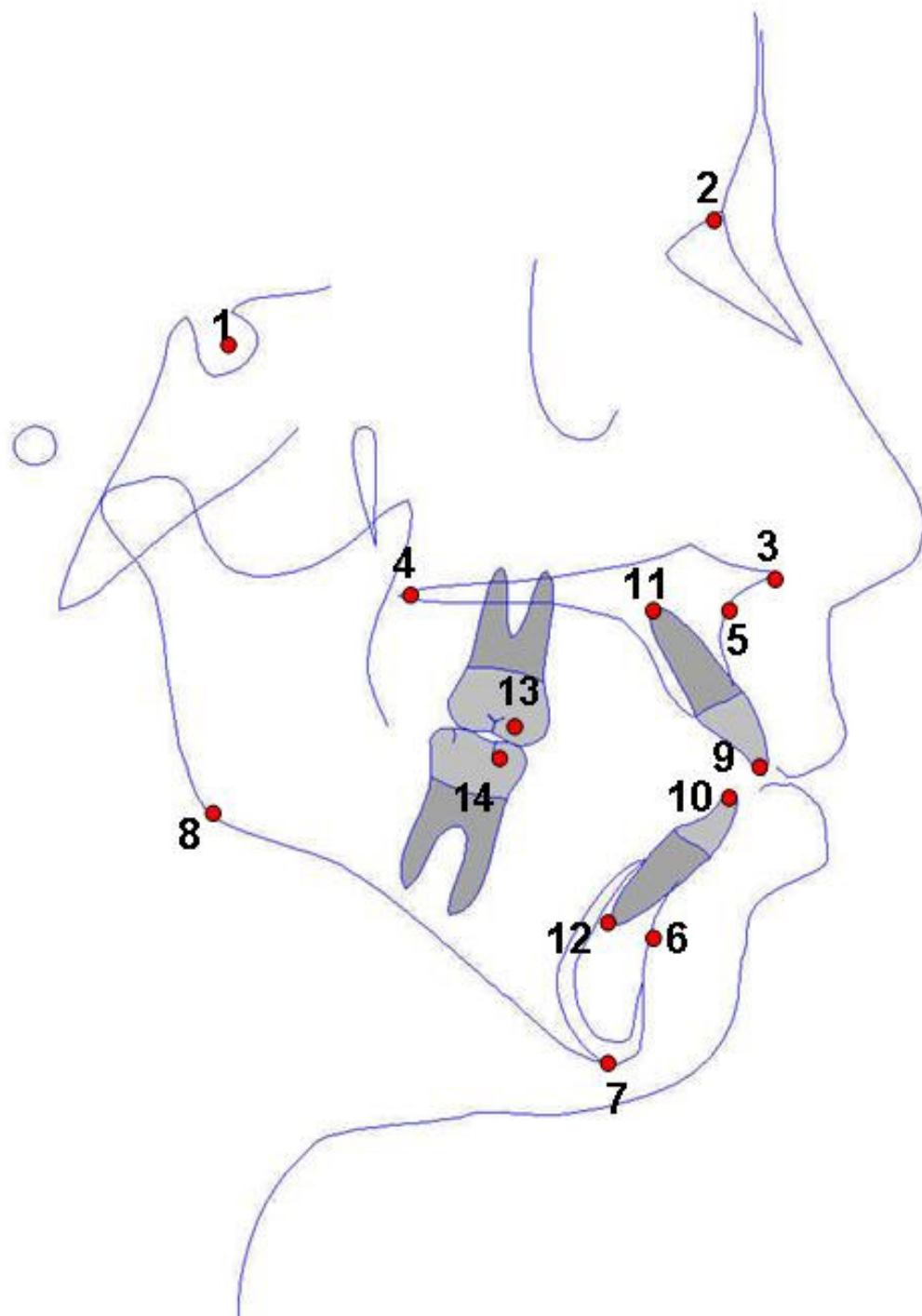


Figure 13. Landmarks used in lateral cephalometric analysis.

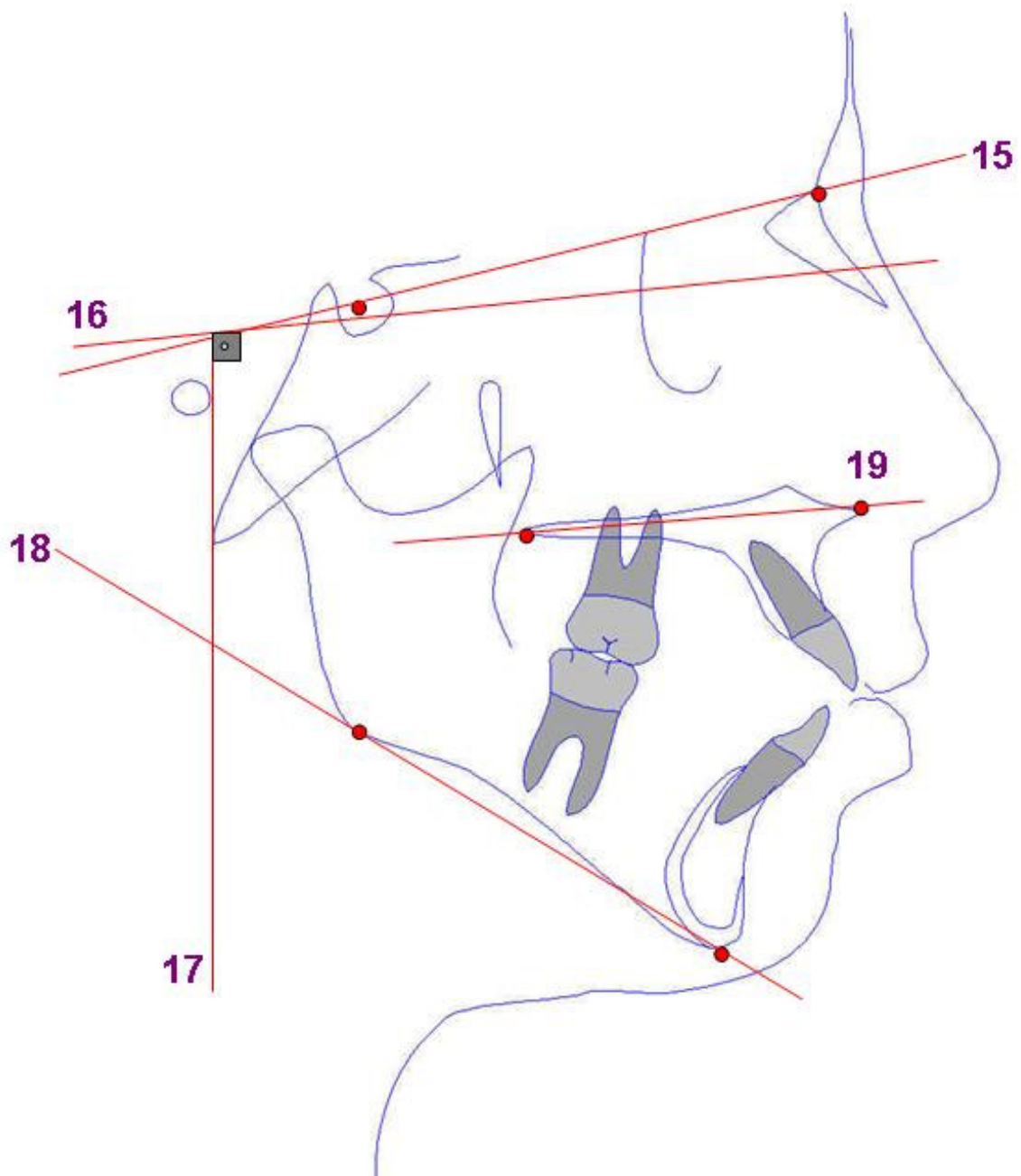


Figure 14. Planes used in lateral cephalometric analysis.

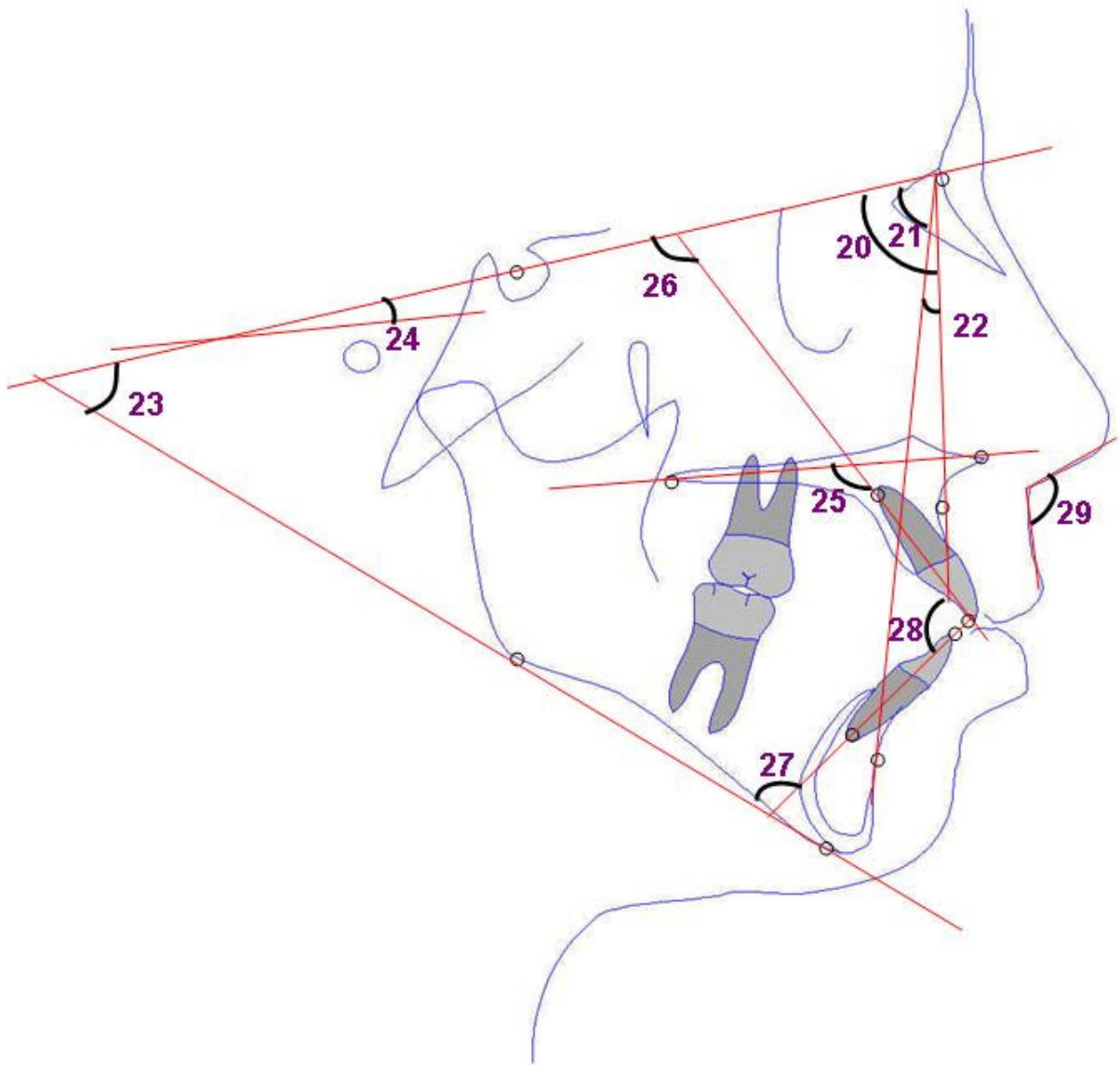


Figure 15. Angular measurements used in lateral cephalometric analysis.

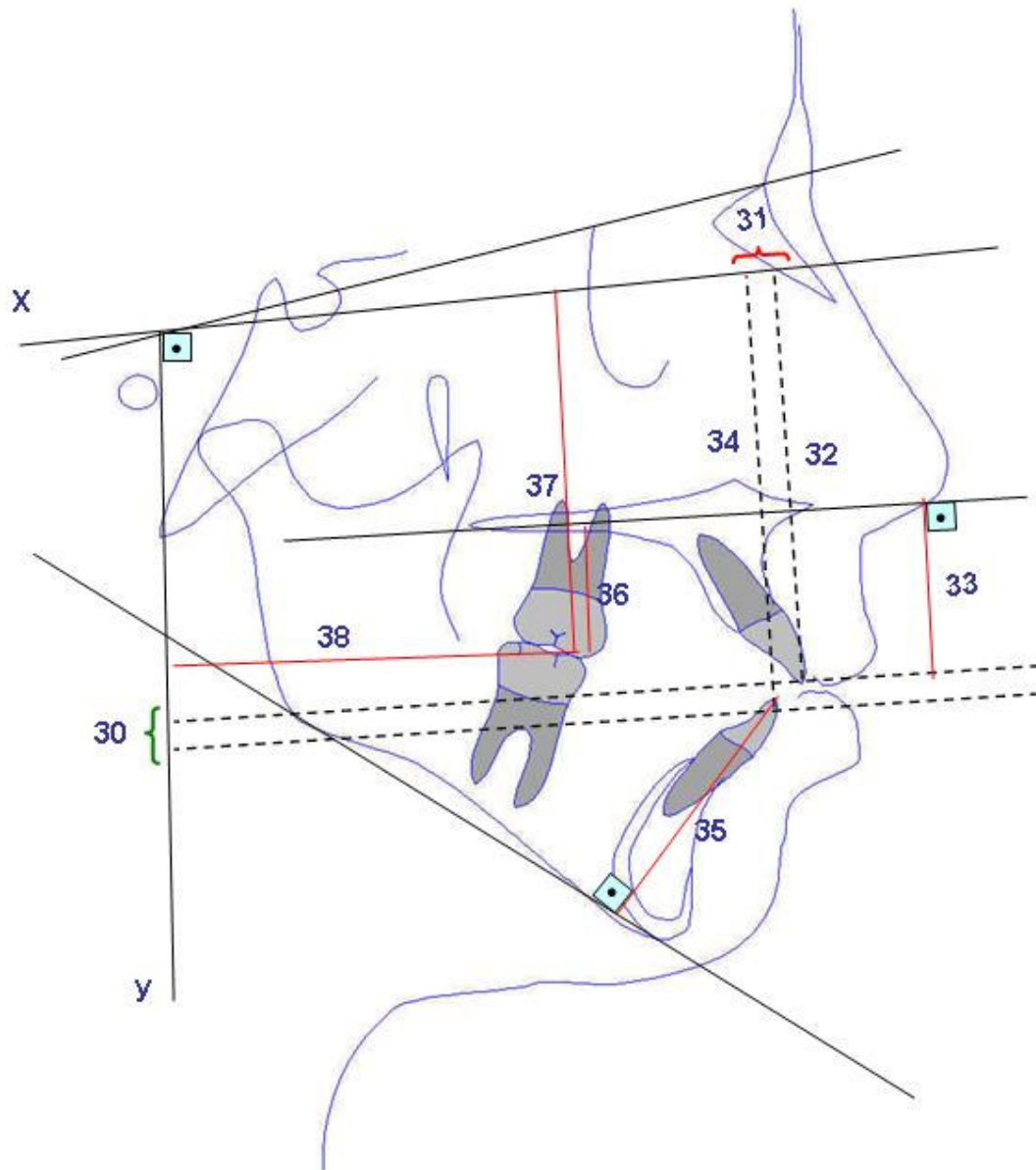


Figure 16.1. Linear measurements used in lateral cephalometric analysis.

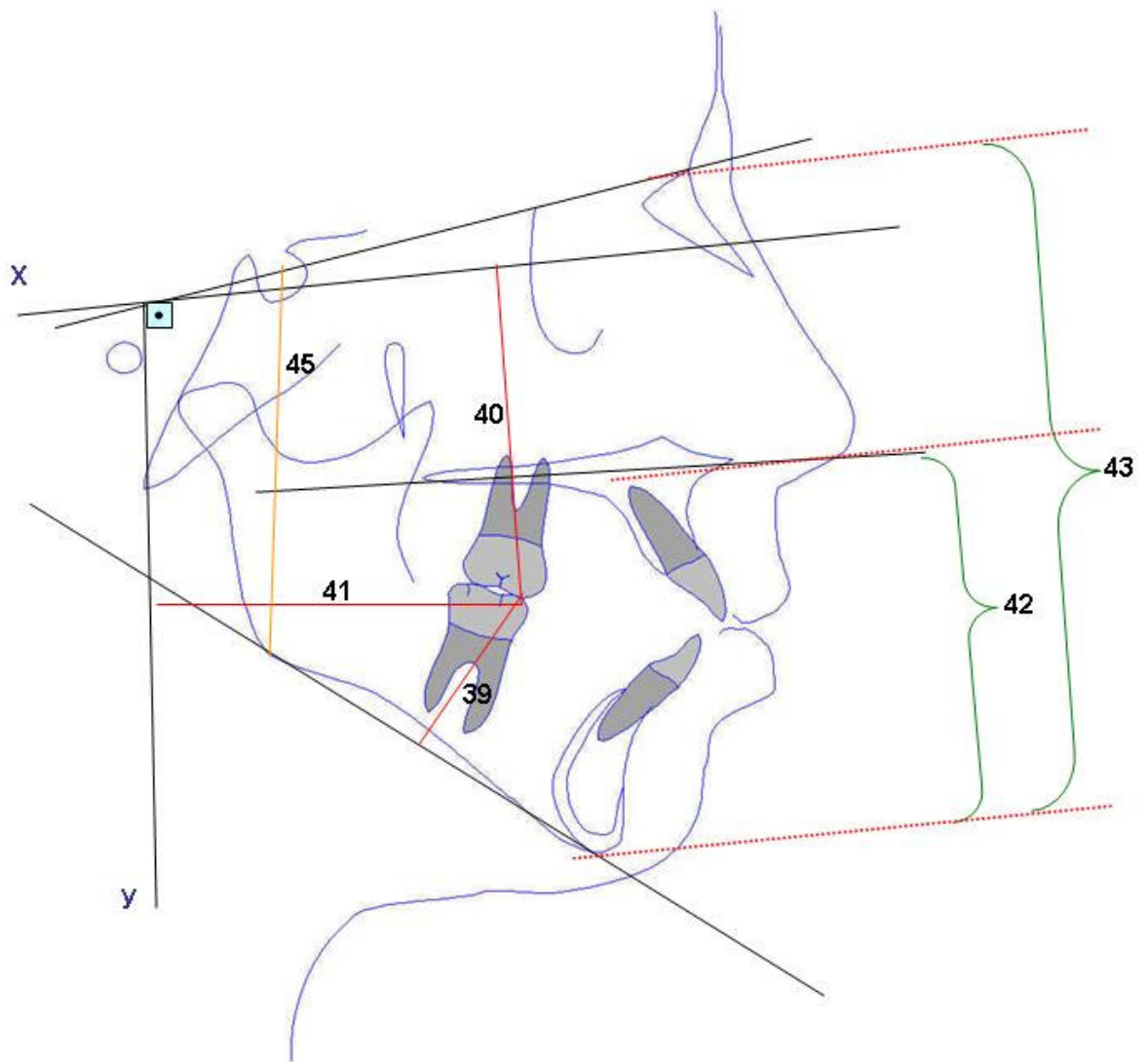


Figure 16.2. Linear measurements used in lateral cephalometric analysis.

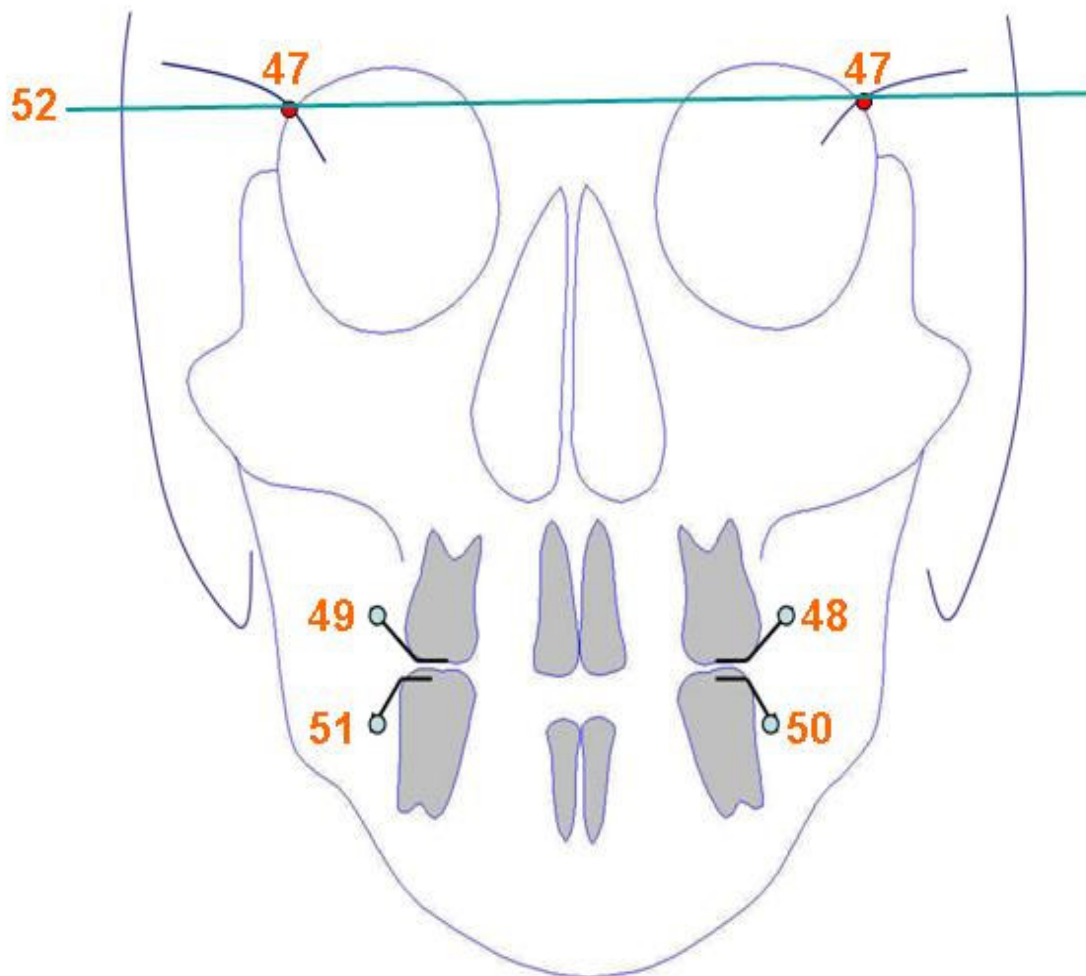


Figure 17. Landmarks and the plane used in postero-anterior cephalometric analysis.

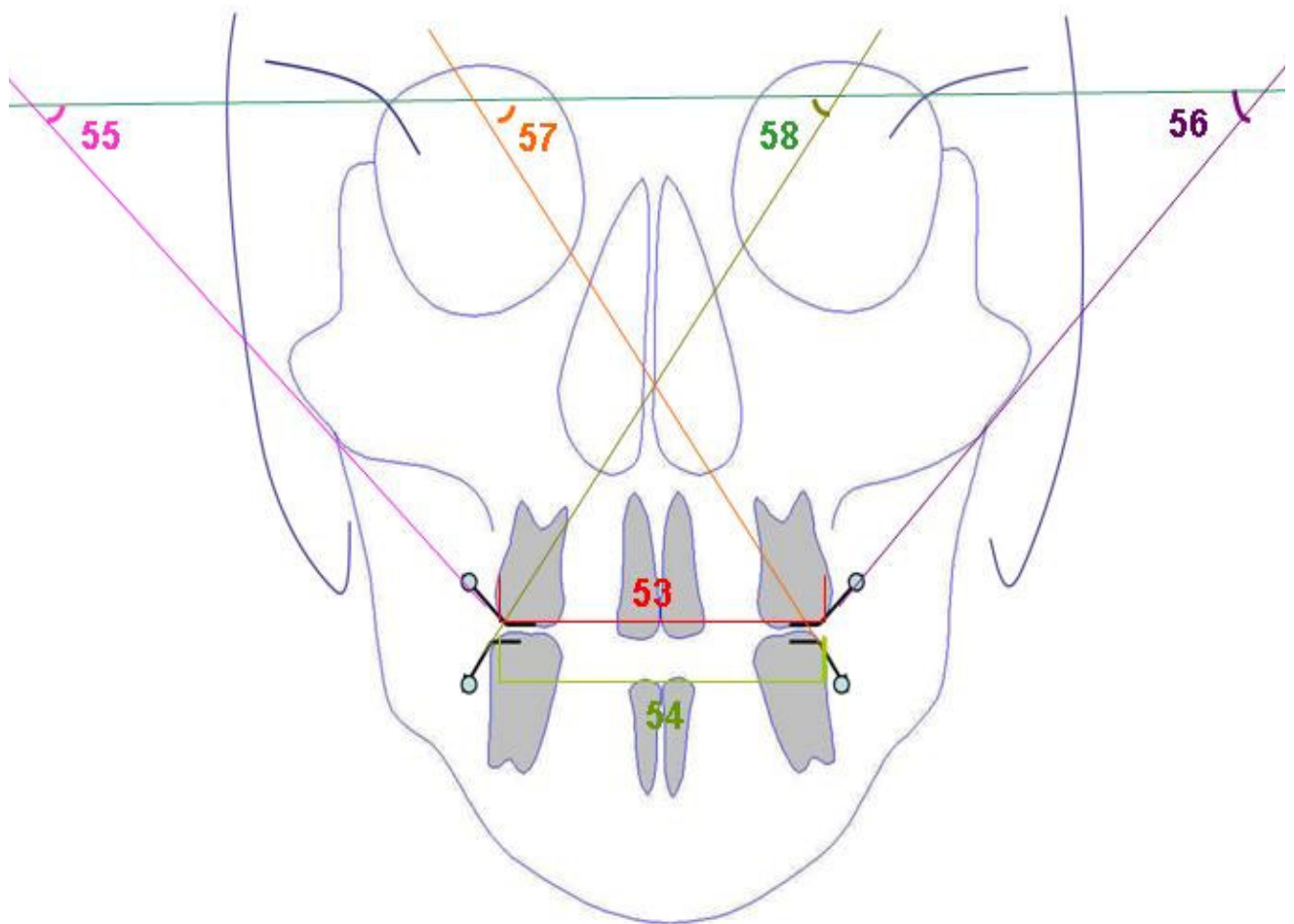


Figure 18. Linear and angular measurements used in postero-anterior cephalometric analysis.

5.8. Statistical Method

Statistical calculations were carried out with NCSS 2007 packet program for Windows. Besides standard descriptive statistical calculations (mean and standard deviation), Friedman test was used in the comparison of groups' repeated times. If the Friedman test (Fr) revealed significance, post Hoc Dunn's multiple comparison test was utilized in the comparison of subgroups. Wilcoxon (Z) was employed in the assessment of pre and post treatment values, Mann Whitney-U test (MW) was used in the comparison of groups and Chi square test was performed during the evaluation of qualitative data. The results were evaluated within a %95 confidence interval. Statistical significance level was established at $p < 0,05$.

5.8.1. Error of the Method

To evaluate measurement error, 5 patients were selected at random and the total pressure measurement procedure was repeated 10 minutes later, at the same appointment by the same observer. For evaluating the intraobserver measurement error in cephalometric tracings, all parameters were traced again by the same observer. The reliability of the repeated measurements were statistically evaluated by calculating the intraclass correlations and intraobserver measurement correspondence.

6. RESULTS

6.1. Crib Appliance Therapy

In order to evaluate the treatment effects of crib appliance of 13 patients in the study group, initial and 10th month lateral cephalometric x-rays were traced. The increase in the vertical distance between upper central incisor tip and X plane (UIT-X), upper incisor tip and palatal plane (UIT-PP), lower incisor tip and mandibular plane (LIT-MP), and inter incisal angle (IIA) were found to be statistically significant ($p < 0.05$). The average IMPA value which was $93,08^\circ \pm 6,66^\circ$, decreased to average $91,27^\circ \pm 8,38^\circ$ ($p = 0.018$). Pretreatment openbite value with an average of $-2,12 \pm 1,12$ mm, increased to average $0,62 \pm 2,08$ mm indicating bite closure ($p = 0.004$) (Table 2., Figure 19.a,b,c).

Table 2. Results of crib appliance therapy

	Pretreatment	10 month Crib Therapy	Z	p
OB	$-2,12 \pm 1,12$	$0,62 \pm 2,08$	-2,85	0,004
UIT-X	$70,46 \pm 5,14$	$73 \pm 4,79$	-3,09	0,002
UIT-PP	$27,77 \pm 3,4$	$29,27 \pm 2,59$	-2,57	0,01
LIT-MP	$40,19 \pm 3,39$	$41,23 \pm 3,51$	-2,69	0.007
IIA	$116,62 \pm 7,64$	$120,46 \pm 8$	-2,17	0,03
IMPA	$93,08 \pm 6,66$	$91,27 \pm 8,38$	-2,20	0,018



Figure 19.a. Crib appliance anterior view



Figure 19.b. Crib appliance occlusal view



Figure 19.c. Bite closure at the end of 10 months

6.2. Measurement Error

All the pressure measurements were repeated in 5 randomly selected patients at the same appointment, and for cephalometric tracings, all parameters were retraced by the same observer. For pressure measurement procedure and cephalometric tracings, intraclass correlation coefficients within the patients, % 95 confidence intervals and intraobserver reliability were calculated. Findings suggest that pressure measurements are reliable and within acceptable limits (Table 3.,4.).

Table 3. Reliability of the pressure measurement.

	Intraclass Correlation Coefficient	%95 Confidence Interval
U6 App. (Rest)	0,971	0,721-0,997
U6 App. (Swallow)	0,996	0,965-0,999
APP. (Rest)	0,810	0,823-0,980
APP. (Swallow)	0,991	0,916-0,999
U6 (Rest)	0,901	0,870-0,986
U6 (Swallow)	0,981	0,817-0,998
L1 (Rest)	0,776	0,651-0,976
L1 (Swallow)	0,918	0,812-0,991
U1 (R)	0,960	0,813-0,995
U1 (S)	0,882	0,798-0,969
Pasta	0,971	0,716-0,996
Çiçek	0,853	0,711-0,984
Dede	0,760	0,610-0,975
Katı	0,914	0,877-0,991

Table 4. Cephalometric tracing reliability

	Intraclass Correlation Coefficient	95% Confidence Interval
SNA	0,9936	0,9542- 0,9991
SNB	0,9957	0,9695- 0,9994
ANB	0,9252	0,4657- 0,9895
SN/MP	0,9898	0,9272- 0,9986
SN/PP	0,9803	0,8591- 0,9972
UI/PP	0,9916	0,9401- 0,9988
UI/SN	0,9964	0,9744- 0,9995
IMPA	0,9988	0,9918- 0,9998
IIA	0,9942	0,9588- 0,9992
NLA	0,9953	0,9663- 0,9993
OB	0,9760	0,8283 -0,9966
OJ	0,9975	0,9821- 0,9996
UIT-X	0,9891	0,9219- 0,9985
UIT-PP	0,9985	0,9894- 0,9998
LIT-X	0,9981	0,9864- 0,9997
LIT-MP	0,9891	0,9218- 0,9985
UMT-PP	0,9954	0,9672- 0,9994
UMT-X	0,9959	0,9709- 0,9994
UMT-Y	0,9731	0,8075- 0,9962
LMT-GM	0,9769	0 ,8349-0,9968
LMT-X	0,9970	0,9787- 0,9996
LMT-Y	0,9936	0,9545- 0,9991
ANS-ME	0,9917	0,9405- 0,9988
N-ME	0,8672	0,7638- 0,9674
ANSMe/NMe	0,9708	0,7911- 0,9959
S-Go	0,9730	0,8071- 0,9962
Jarabak	0,9592	0,8087- 0,9943
UIMW	0,9524	0,8597- 0,9933
LIMW	0,9991	0,9933 -0,9999
URMA	0,9995	0,9967- 0,9999
ULMA	0,9995	0,9967- 0,9999
LRMA	0,9248	0,7627- 0,9895
LLMA	0,9992	0,9943 -0,9999

6.3. Study and Control Group Homogeneity

Initial lateral cephalograms of both the study and control groups were traced; medians and standard deviations of all parameters were calculated and evaluated by

Mann-Whitney-U test. According to the results, the differences between the values for study and control group were statistically insignificant ($p>0.05$), indicating homogeneity between the two groups (Table 5.).

Table 5. Study and control group homogeneity.

Pretreatment	Study Group	Control Group	MW	P
SNA	78,73±3,91	80,08±4,36	33	0,598
SNB	73,54±4,37	73,17±4,75	36,5	0,825
ANB	5,27±1,39	7,08±2,2	20	0,089
SN/MP	43,35±6,27	44,83±5	34	0,66
SN/PP	9,15±3,05	9,33±3,08	37	0,859
U1/PP	117,46±6,8	115,33±10,61	33	0,598
U1/SN	107,81±6,55	105,25±7,03	27,5	0,311
IMPA	93,08±6,66	94,17±5,64	34	0,66
IIA	116,62±7,64	117,42±13,48	37	0,861
NLA	110,46±9,18	117,42±9,4	21,5	0,124
OB	-2,12±1,12	-2,83±2,07	33,5	0,613
OJ	5,65±1,92	6,08±2,85	35	0,724
UIT-X	70,46±5,14	69,33±3,6	36	0,792
UIT-PP	27,77±3,4	26,5±3,44	32,5	0,568
LIT-X	72,19±5,07	71,83±3,53	32,5	0,567
LIT-MP	40,19±3,39	39,5±3,33	35,5	0,758
UMT-PP	20,85±1,55	21,08±1,69	33	0,592
UMT-X	62,42±3,52	62,42±3,29	38	0,93
UMT-Y	30,54±5,87	33±4,9	27,5	0,312
LMT-GM	29,88±2,69	29,67±1,78	36,5	0,823
LMT-X	64,54±3,47	63,17±3,19	29	0,377
LMT-Y	32,31±6,28	32,92±4,78	32,5	0,566
ANS-ME	65,38±4,95	63,33±3,56	29	0,379
N-ME	117,23±7,25	115±4,27	34,5	0,693
ANSMe/NMe	55,69±1,84	55,03±2,16	26	0,254
S-Go	69,88±4,22	67,67±1,97	24	0,186
Jarabak	58,7±3,69	58,2±2,86	38,5	0,965
UIMW	56,42±3,16	54,17±2,64	20,5	0,102
LIMW	50±2,88	50,17±3,54	38,5	0,965
URMA	60±13,29	61,33±11,09	38	0,93
ULMA	63,46±11,45	60±13,18	34	0,661
LRMA	39,89±8,87	46,42±11,78	27,5	0,313
LLMA	40±8,19	43,33±9,18	36,5	0,826

6.4. Tongue Pressure Measurements in Study Group

6.4.1. Pressure Changes on Upper First Molar

6.4.1.1. Pressure Changes in Rest Position

According to the pretreatment measurements in the study group, the average resting tongue pressure on the palatal side of upper first molar was $16,66 \pm 6,37$ gr/cm². Inserting the crib appliance in the mouth, and the average resting tongue pressure on the palatal side of upper first molar increased up to $27,17 \pm 11,56$ gr/cm². This increase was statistically insignificant when compared with pretreatment values ($p > 0.05$). The following 1st week and 1st month, resting pressures showed slight decrease. The average resting pressures were $21,34 \pm 10,95$ gr/cm² and $20,17 \pm 12,93$ gr/cm² respectively which were insignificant when compared with pretreatment and appliance insertion values ($p > 0.05$). At the 3rd month, the average resting pressure was measured as $17,62 \pm 10,75$ gr/cm², the difference being insignificant when compared with pretreatment, appliance insertion, 1st week and 1st month values ($p > 0.05$). The average resting pressure continued decreasing and at the 6th month was found to be $12,86 \pm 2,84$ gr/cm². The difference was still statistically insignificant when compared with average pretreatment, 1st week, 1st month and 3rd month values ($p > 0.05$), while it was significant relative to the average appliance insertion value ($p < 0.01$). At the 10th month, the average resting pressure value decreased to $12,17 \pm 1,45$ gr/cm². The difference between the 10th month and appliance insertion value was significant ($p < 0.001$) while it was insignificant when compared with pretreatment, 1st week, 1st month, 3rd month and 6th month values ($p > 0.05$). Again, at the 10th month, right after the appliance removal, the average resting pressure was measured as $12 \pm 3,65$ gr/cm². The difference between the 10th month appliance removal and appliance insertion values was significant ($p < 0.001$), while it was found insignificant when compared with average pretreatment, 1st week, 1st month, 6th month, 10th month values. Two months after the appliance removal; at the 12th month, the average resting pressure slightly increased up to $12,57 \pm 3,65$ gr/cm² but still being lower than pretreatment values. The difference between the 12th month and appliance insertion values was significant ($p < 0.001$) whereas, the difference between the 12th month average resting pressure and pretreatment, 1st week, 1st month, 3rd month, 6th month and 10th month values were found to be insignificant ($p > 0.05$) (Table 6.1., 6.2., Figure 20.).

6.4.1.2. Pressure Changes during Swallowing

According to the pretreatment pressure measurements, the average tongue pressure on the palatal side of upper first molar during swallowing was $149,86 \pm 28,28$ gr/cm². During the same appointment, the average pressure increased up to $186,34 \pm 52,8$ gr/cm² right after the insertion of the crib appliance. This increase was statistically insignificant ($p > 0.05$). The following 1st week, the average tongue pressure was measured as $197,89 \pm 65,69$ gr/cm². This increase was also insignificant when compared with pretreatment and appliance insertion values ($p > 0.05$). Measurements in the 1st and 3rd month revealed a slight decrease and the average tongue pressure values were $170,62 \pm 46,35$ gr/cm² and $171,92 \pm 48,06$ gr/cm² respectively which were also insignificant relative to the pretreatment, appliance insertion and 1st week values ($p > 0.05$). At the 6th month, the average tongue pressure dropped to $151,75 \pm 13,03$ gr/cm² which was also insignificant when compared with previous measurements. At the 10th month, the average swallowing pressure continued decreasing and was measured as $141,95 \pm 14,9$ gr/cm² which was insignificant relative to the previous measurement values. The average swallowing pressure right after the appliance removal at the 10th month was $135,42 \pm 18,17$ gr/cm². This value was significant relative to the appliance insertion value ($p < 0.05$) and 1st week value ($p < 0.01$) while it was insignificant when compared with pretreatment, 1st month, 3rd month, 6th month and 10th month values ($p > 0.05$). Two months after the appliance removal; at the 12th month, the average swallowing pressure showed a slight increase approaching pretreatment values, which was measured as $150,68 \pm 20,88$ gr/cm². This value was statistically insignificant when compared with pretreatment, appliance insertion, 1st week, 1st month, 3rd month, 6th month, 10th month and 10th month appliance removal values ($p > 0.05$) (Table 6.1, 6.2., Figure 20.).

Table 6.1. Median, mean and standard deviation pressure values for upper first molar during rest and swallow.

U6	Median	U6 (R)	Median	U6 (S)
Pretreatment	13,4	16,66±6,37	153,2	149,86±28,28
Appliance insertion	22,4	27,17±11,56	183,6	186,34±52,8
1st week	15	21,34±10,95	183,4	197,89±65,69
1st month	16	20,17±12,93	159,6	170,62±46,35
3rd month	14,4	17,62±10,75	160	171,92±48,06
6th month	12,4	12,86±2,84	147,6	151,75±13,03
10th month	12,2	12,17±1,45	142,4	141,95±14,9
10th month (App. Removal)	13	12±3,65	133	135,42±18,17
12th month	12,4	12,57±3,65	150,2	150,68±20,88
Fr		37,82		23,97
P		0,0001		0,002

Table 6.2. Statistical significance table for upper first molar pressure measurements during rest and swallow.

Dunn's Multiple Comparison Test	U6 (R)	U6 (S)
Pretreatment / Appliance insertion	P > 0.05	P > 0.05
Pretreatment / 1 st week	P > 0.05	P > 0.05
Pretreatment / 1 st month	P > 0.05	P > 0.05
Pretreatment / 3 rd month	P > 0.05	P > 0.05
Pretreatment / 6 th month	P > 0.05	P > 0.05
Pretreatment / 10 th month	P > 0.05	P > 0.05
Pretreatment / 10 th month (app. removal)	P > 0.05	P > 0.05
Pretreatment / 12 th month	P > 0.05	P > 0.05
Appliance insertion / 1 st week	P > 0.05	P > 0.05
Appliance insertion / 1 st month	P > 0.05	P > 0.05
Appliance insertion / 3 rd month	P > 0.05	P > 0.05
Appliance insertion / 6 th month	P < 0.01	P > 0.05
Appliance insertion / 10 th month	P < 0.001	P > 0.05
Appliance insertion / 10 th month (app. removal)	P < 0.001	P < 0.05
Appliance insertion / 12 th month	P < 0.001	P > 0.05
1 st week / 1 st month	P > 0.05	P > 0.05
1 st week/ 3 rd month	P > 0.05	P > 0.05
1 st week/ 6 th month	P > 0.05	P > 0.05
1 st week/ 10 th month	P > 0.05	P > 0.05
1 st week/ 10 th month (app. removal)	P > 0.05	P < 0.01
1 st week/ 12 th month	P > 0.05	P > 0.05
1 st week/ 3 rd month	P > 0.05	P > 0.05
1 st month / 6 th month	P > 0.05	P > 0.05
1 st month / 10 th month	P > 0.05	P > 0.05
1 st month / 10 th month (app. removal)	P > 0.05	P > 0.05
1 st month / 12 th month	P > 0.05	P > 0.05
3 rd month / 6 th month	P > 0.05	P > 0.05
3 rd month / 10 th month	P > 0.05	P > 0.05
3 rd month/ 10 th month (app. removal)	P > 0.05	P > 0.05
3 rd month / 12 th month	P > 0.05	P > 0.05
6 th month / 10 th month	P > 0.05	P > 0.05
6 th month / 10 th month (app. removal)	P > 0.05	P > 0.05
6 th month/ 12 th month	P > 0.05	P > 0.05
10 th month / 10 th month (app. removal)	P > 0.05	P > 0.05
10 th month / 12 th month	P > 0.05	P > 0.05
10 th month (app. removal) / 12 th month	P > 0.05	P > 0.05

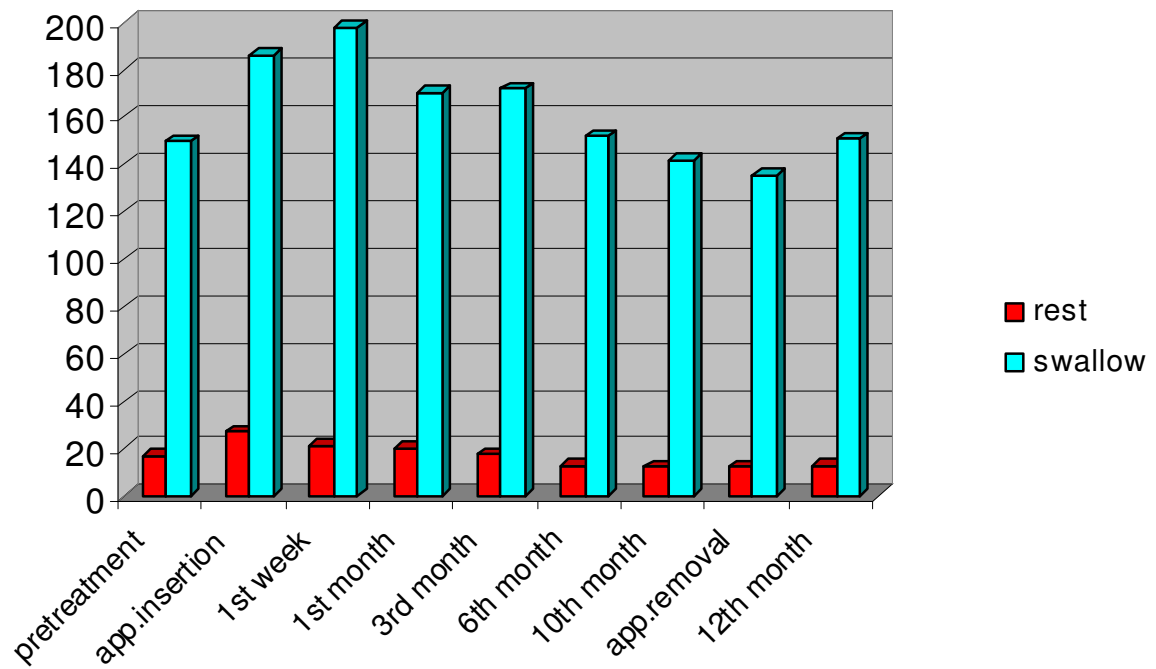


Figure 20. Graph displaying tongue pressure changes in gr/cm², on upper first molar during rest and swallowing.

6.4.2. Pressure Changes on Upper Incisor

6.4.2.1. Pressure Changes in Rest Position

The average pretreatment resting tongue pressure on the palatal side of upper central incisor was measured as $16,42 \pm 8,95 \text{ gr/cm}^2$. At the 10th month, right after the removal of the crib appliance, the average resting pressure was measured as $13,31 \pm 2,46 \text{ gr/cm}^2$. This decrease was statistically insignificant when compared with pretreatment value ($p > 0.05$). Two months after the removal of the crib appliance, the measurements at the 12th month revealed an average of $11,63 \pm 4,7 \text{ gr/cm}^2$. Although the average resting pressure continued decreasing even 2 months after the removal of the crib appliance; the difference was still statistically insignificant relative to the pretreatment values ($p > 0.05$) (Table 7.1., Figure 21.).

6.4.2.2. Pressure Changes during Swallowing

The average pretreatment swallowing pressure on the palatal side of upper central incisor was measured as $154,12 \pm 41,12 \text{ gr/cm}^2$. At the 10th month, right after the removal of the crib appliance, the average swallowing pressure was measured as $128,59 \pm 16,78 \text{ gr/cm}^2$. This decrease was statistically insignificant when compared with pretreatment value ($p > 0.05$). Two months after the removal of the crib appliance, the measurements at the 12th month revealed a slight increase with an average of $136,82 \pm 17,42 \text{ gr/cm}^2$. This finding was also statistically insignificant when compared with lower 10th month and higher pretreatment values ($p > 0.05$) (Table 7.1., Figure 21.).

6.4.2.3. Pressure Changes during Pronunciation

Pretreatment average pressure value for the pronunciation of the word 'pasta' was $31,75 \pm 12,68 \text{ gr/cm}^2$. At the 10th month, right after the removal the crib appliance, it was measured as $22,15 \pm 5,21 \text{ gr/cm}^2$. Two months after the removal of the crib appliance; at the 12th month, the average pressure value was $23,79 \pm 5,74 \text{ gr/cm}^2$. The differences between all the measurement times were statistically insignificant although there was a decrease relative to the pretreatment value ($p > 0.05$).

Pretreatment average pressure value for the pronunciation of the word 'çiçek' was $31,28 \pm 6,35 \text{ gr/cm}^2$. At the 10th month, right after the removal the crib appliance, it was measured as $22,25 \pm 7,37 \text{ gr/cm}^2$. Two months after the removal of the crib

appliance; at the 12th month, the average pressure value was $23,88 \pm 3,61$ gr/cm². The decrease between pretreatment-10th month and pretreatment-12th month values were statistically significant ($p < 0.05$). The difference between 10th month-12th month values were statistically insignificant ($p > 0.05$).

Pretreatment average pressure value for the pronunciation of the word 'dede' was $32,37 \pm 9,14$ gr/cm². At the 10th month, right after the removal the crib appliance, it was measured as $22,91 \pm 6,17$ gr/cm². Two months after the removal of the crib appliance; at the 12th month, the average pressure value was $24 \pm 6,9$ gr/cm². The decrease between pretreatment-10th month and pretreatment-12th month values were statistically significant ($p < 0.05$). The difference between 10th month-12th month values were statistically insignificant ($p > 0.05$).

Pretreatment average pressure value for the pronunciation of the word 'katı' was $31,49,37 \pm 13,40$ gr/cm². At the 10th month, right after the removal the crib appliance, it was measured as $23,31 \pm 7,66$ gr/cm². Two months after the removal of the crib appliance; at the 12th month, the average pressure value was $23,28 \pm 6,15$ gr/cm². The decrease between pretreatment-10th month values was statistically significant ($p < 0.05$). The difference between pretreatment-10th month and 10th month-12th month values were statistically insignificant ($p > 0.05$) (Table 7.2., 7.2.a., Figure 22.).

Table 7.1. Median, mean and standard deviation pressure values in gr/cm² for upper central incisor during rest and swallowing.

	Median	U1 (R)	median	U1 (S)
Pretreatment	16,4	16,42±8,95	142,8	154,12±41,12
10th month	13,8	13,31±2,46	130,6	128,59±16,78
12th month	11,4	11,63±4,7	133,2	136,82±17,42
Fr		4,34		3,71
P		0,113		0,156

Table 7.2. Pressure values on the palatal side of upper central incisor in gr/cm² during pronunciation.

	Median	Pasta	median	Çiçek	median	Dede	median	Katı
Pretreatment	25,2	31,75±12,68	30,2	31,28±6,35	31	32,37±9,14	29,8	31,49±13,40
10th month	23,2	22,15±5,21	21	22,25±7,37	22,6	22,91±6,17	20,8	23,31±7,66
12th month	22,8	23,79±5,74	23,4	23,88±3,61	22,6	24±6,9	21,2	23,28±6,15
Fr		4,73		10,88		10,06		8,03
P		0,093		0,004		0,006		0,018

Table 7.2.a. Statistical significance table for upper central incisor during pronunciation.

Dunn's Multiple Comparison Test	Çiçek	Dede	Katı
Pretreatment / 10th month	P < 0.01	P < 0.05	P < 0.05
Pretreatment / 12th month	P < 0.05	P < 0.05	P > 0.05
10th month / 12th month	P > 0.05	P > 0.05	P > 0.05

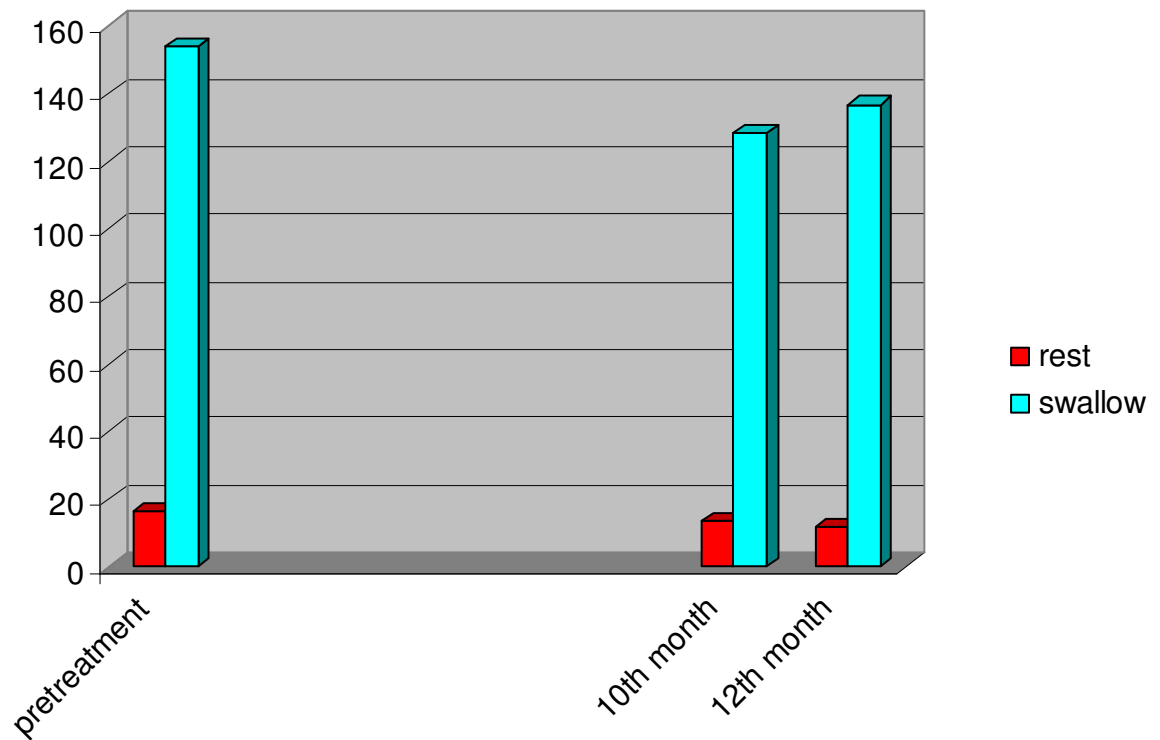


Figure 21. Graph displaying tongue pressure changes gr/cm^2 acting on upper central incisor during rest and swallowing.

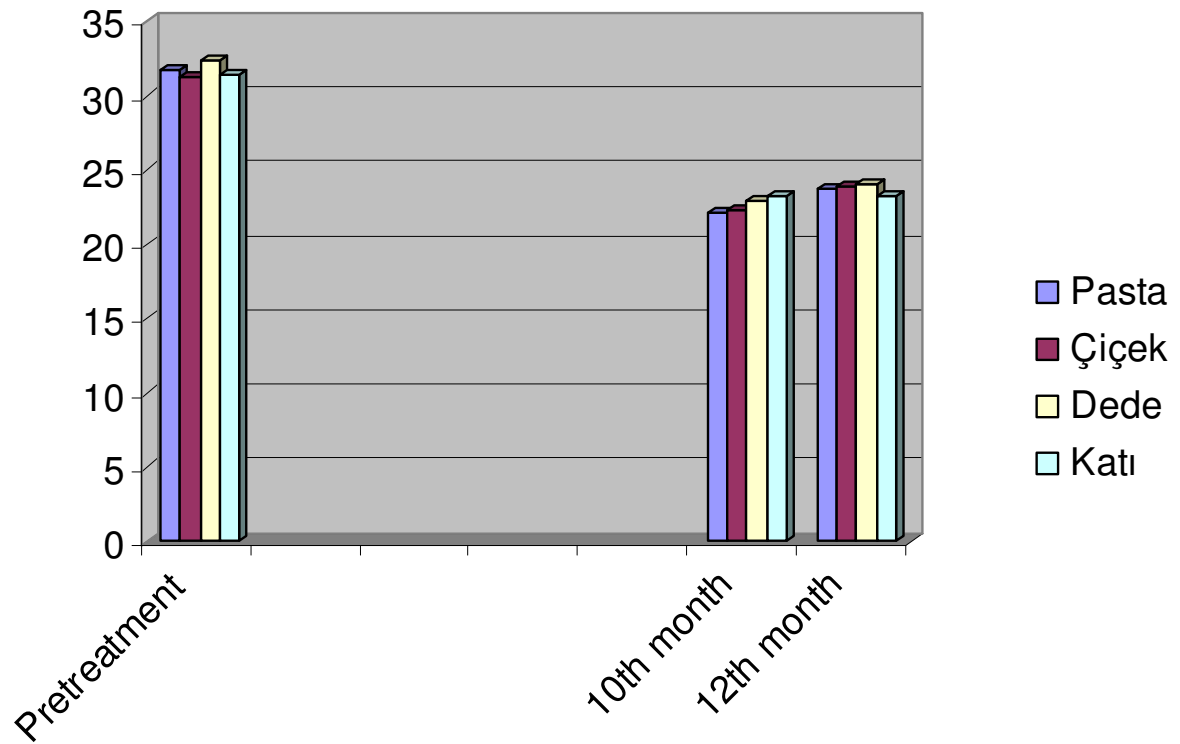


Figure 22. Graph displaying tongue pressure changes in gr/cm², acting on upper central incisor during pronunciation .

6.4.3. Evaluation of Pressure Changes on Lower Incisor

6.4.3.1. Evaluation of Pressure Changes in Rest Position

The average pretreatment resting pressure on the lingual side of lower central incisor was measured as $15,26 \pm 5,27 \text{ gr/cm}^2$. At the 10th month, right after the removal of the crib appliance, the average resting pressure was measured as $11,83 \pm 2,98 \text{ gr/cm}^2$. This decrease was statistically insignificant when compared with pretreatment value ($p > 0.05$). Two months after the removal of the crib appliance, the measurements at the 12th month revealed an average of $11,91 \pm 4,85 \text{ gr/cm}^2$. Although the average resting pressure decreased at 12 month period, the differences between all the times were statistically insignificant. ($p > 0.05$) (Table 8., Figure 23.).

6.4.3.2. Evaluation of Pressure Changes During Swallowing

The average pretreatment resting pressure on the lingual side of lower central incisor was measured as $15,26 \pm 5,27 \text{ gr/cm}^2$. At the 10th month, right after the removal of the crib appliance, the average resting pressure was measured as $11,83 \pm 2,98 \text{ gr/cm}^2$. This decrease was statistically insignificant when compared with pretreatment value ($p > 0.05$). Two months after the removal of the crib appliance, the measurements at the 12th month revealed an average of $11,91 \pm 4,85 \text{ gr/cm}^2$. Although the average resting pressure decreased in 12 month period, the differences between all the times were statistically insignificant. ($p > 0.05$) (Table 8., Figure 23.).

Table 8. Median, mean and standard deviation pressure values for lower central incisor during rest and swallow.

	Median	L1 (R)	median	L1 (S)
Pretreatment	15,2	$15,26 \pm 5,27$	136,4	$138,25 \pm 29,57$
10th month	12,6	$11,83 \pm 2,98$	129,4	$129,82 \pm 20,36$
12th month	12,4	$11,91 \pm 4,85$	137,2	$138,08 \pm 16,56$
Fr		3,79		1,32
P		0,149		0,516

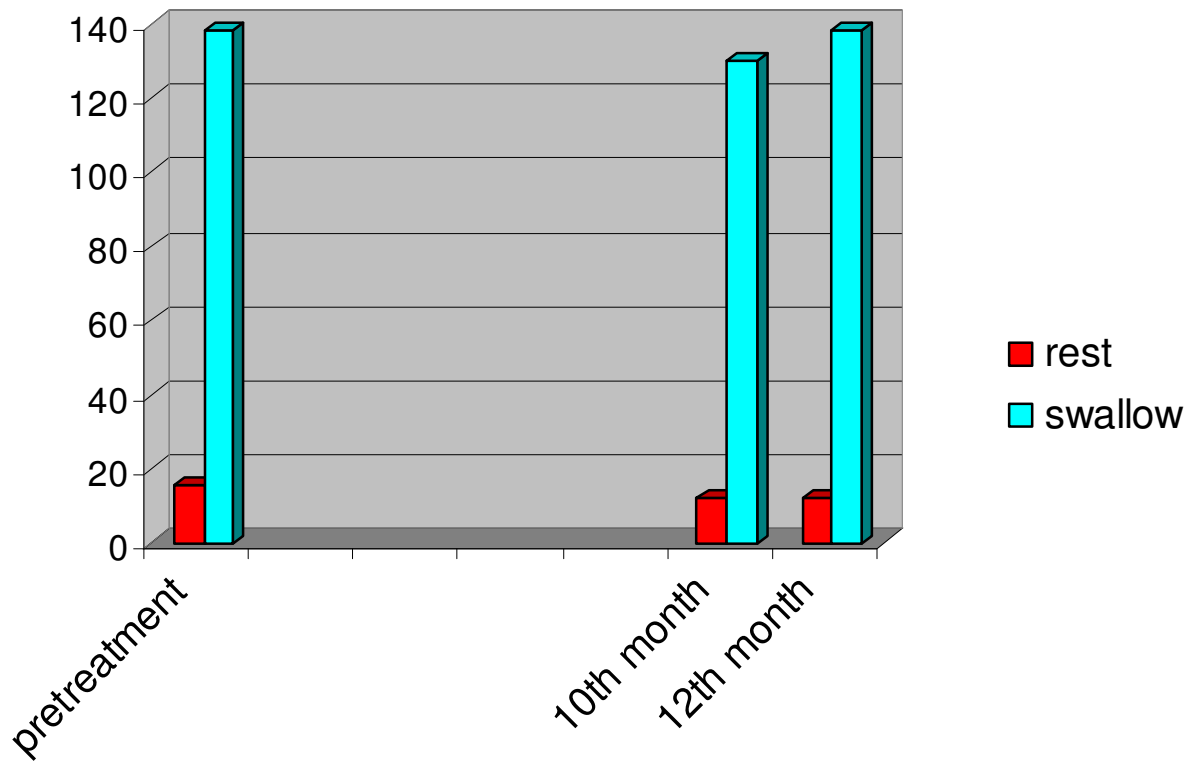


Figure 23. Graph displaying pressure changes in gr/cm², acting on lower central incisor during rest and swallowing.

6.4.4. Evaluation of Pressure Changes on Crib Appliance

6.4.4.1. Evaluation of Pressure Changes in Rest Position

The average resting pressure on the crib appliance at the time of insertion was measured as $21,09 \pm 14,55 \text{ gr/cm}^2$. In the first week, the average pressure decreased to $18,91 \pm 14,18 \text{ gr/cm}^2$ which was statistically insignificant ($p > 0.05$). At the 1st month and 3rd month the average resting pressure values were measured as $22,03 \pm 12,52 \text{ gr/cm}^2$ and $17,69 \pm 12,49 \text{ gr/cm}^2$ respectively which were also statistically insignificant when compared with pretreatment and 1st week values. At the 6th month the pressure showed an insignificant decrease with an average value of $13,57 \pm 2,67 \text{ gr/cm}^2$ ($p > 0.05$). At the 10th month average resting pressure value continued decreasing with an average value of $12,8 \pm 2,41 \text{ gr/cm}^2$. The decrease in average resting pressure between 1st month and 10th month values was statistically significant ($p < 0.05$) (Table 9.1., 9.2., Figure 24.).

6.4.4.2. Evaluation of Pressure Changes during Swallowing

The average swallowing pressure on the crib appliance at the time of insertion was measured as $216,43 \pm 65,79 \text{ gr/cm}^2$. In the first week, the average pressure decreased to $192,92 \pm 58,33 \text{ gr/cm}^2$. The difference between the beginning and the 1st week values was statistically insignificant ($p > 0.05$). At the 1st, 3rd and 6th months, the average swallowing pressure was measured as $179,09 \pm 57,13 \text{ gr/cm}^2$, $171,43 \pm 60,29 \text{ gr/cm}^2$, and $158,02 \pm 35,83 \text{ gr/cm}^2$ respectively. Although the average swallowing pressure continued declining in 6 months time, the differences between all the times were statistically insignificant ($p > 0.05$). At the 10th month, the average swallowing pressure showed the lowest value and was measured as $142,95 \pm 29,2 \text{ gr/cm}^2$. The decrease in swallowing pressure between the beginning and 10th month values was statistically significant ($p < 0.05$) (Table 9.1., 9.2., Figure 24.).

Table 9.1. Median, mean and standard deviation pressure values on crib appliance during rest and swallow.

Appliance	App. (R)		App. (S)	
App. insertion	20,8	21,09±14,55	208,2	216,43±65,79
1st week	15,2	18,91±14,18	186	192,92±58,33
1st month	17,2	22,03±12,52	154,6	179,09±57,13
3rd month	14	17,69±12,49	164,4	171,43±60,29
6th month	13,2	13,57±2,67	157,2	158,02±35,83
10th month	13,2	12,8±2,41	136,4	142,95±29,2
Fr	12,67		13,86	
P	0,02		0,016	

Table 9.2. Statistical significance table for pressures acting on crib appliance during rest and swallowing.

Dunn's Multiple Comparison Test	App. (R)	App. (S)
Pretreatment / 1 st week	P > 0.05	P > 0.05
Pretreatment / 1 st month	P > 0.05	P > 0.05
Pretreatment/ 3 rd month	P > 0.05	P > 0.05
Pretreatment / 6 th month	P > 0.05	P > 0.05
Pretreatment / 10 th month	P > 0.05	P < 0.05
1 st week/ 1 st month	P > 0.05	P > 0.05
1 st week/ 3 rd month	P > 0.05	P > 0.05
1 st week/ 6 th month	P > 0.05	P > 0.05
1 st week / 10 th month	P > 0.05	P > 0.05
1 st month/ 3 rd month	P > 0.05	P > 0.05
1 st month / 6 th month	P > 0.05	P > 0.05
1 st month / 10 th month	P < 0.05	P > 0.05
3 rd month / 6 th month	P > 0.05	P > 0.05
3 rd month / 10 th month	P > 0.05	P > 0.05
6 th month / 10 th month	P > 0.05	P > 0.05

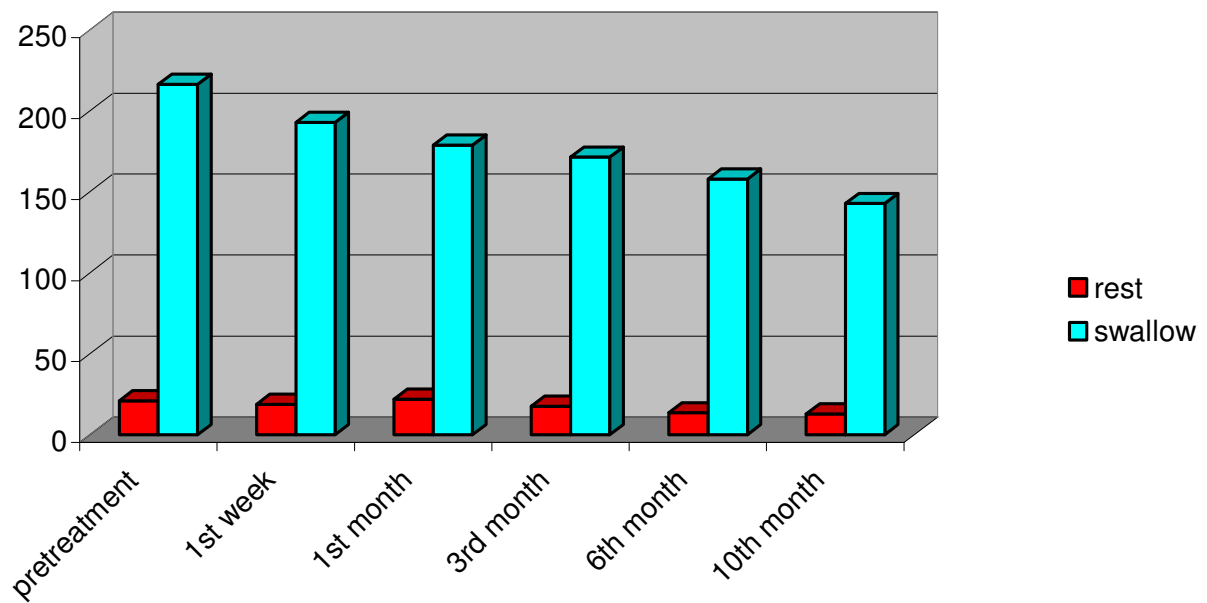


Figure 24. Graph displaying tongue pressure changes in gr/cm^2 , acting on crib appliance during rest and swallowing.

6.5. Pressure Measurements in Control Group

6.5.1. Pressure Changes on Upper First Molar

6.5.1.1. Pressure Changes in Rest Position

The average resting pressure on the palatal side of upper first molar at the beginning was measured as $18,97 \pm 4,92 \text{ gr/cm}^2$. At the 10th and 12th months, the average resting pressure was $19,9 \pm 6,47 \text{ gr/cm}^2$ and $19,13 \pm 5,81 \text{ gr/cm}^2$ respectively. The differences between the beginning, 10th month and 12th month values were statistically insignificant ($p > 0.05$) (Table 10., Figure 25.).

6.5.1.2. Pressure Changes during Swallowing

The average swallowing pressure on the palatal side of upper first molar in the beginning was measured as $166,7 \pm 26,47 \text{ gr/cm}^2$. At the 10th and 12th months, the average pressure values were $142,47 \pm 14,12 \text{ gr/cm}^2$ and $143,73 \pm 15,86 \text{ gr/cm}^2$ respectively. The differences between the beginning, 10th month and 12th month values were statistically insignificant ($p > 0.05$) (Table 10., Figure 25.).

Table 10. Mean and standard deviation pressure values on upper first molar during rest and swallowing in control group.

Control Group	U6 (R)	U6 (S)
Beginning	18,97±4,92	166,7±26,47
10 th month	19,9±6,47	142,47±14,12
12 th month	19,13±5,81	143,73±15,86
Fr	0,33	0,35
P	0,956	0,958

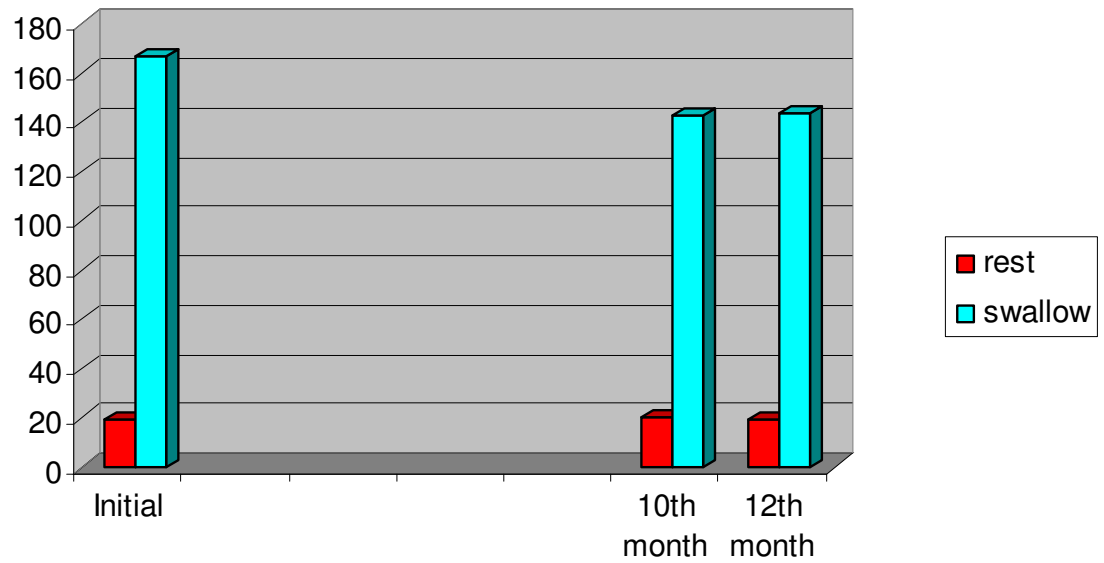


Figure 25. Graph displaying tongue pressure changes in gr/cm^2 , acting on upper first molar during rest and swallowing in control group.

6.5.2. Pressure Changes on Upper Central Incisor

6.5.2.1. Pressure Changes in Rest Position

The initial average resting tongue pressure on the palatal side of upper central incisor was measured as $19,5 \pm 14,95 \text{ gr/cm}^2$. The average resting pressures at the 10th month and 12th month were $16,93 \pm 3,46 \text{ gr/cm}^2$ and $19,1 \pm 3,79 \text{ gr/cm}^2$ respectively. The differences between the initial, 10th month and 12th month values were statistically insignificant ($p > 0.05$) (Table 11.1., Figure 26.).

6.5.2.2. Pressure Changes during Swallowing

The initial average swallowing tongue pressure on the palatal side of upper central incisor was measured as $148,53 \pm 23,09 \text{ gr/cm}^2$. The average resting pressures at the 10th month and 12th month were $143,4 \pm 26,74 \text{ gr/cm}^2$ and $150,37 \pm 28,1 \text{ gr/cm}^2$ respectively. The differences between the initial, 10th month and 12th month values were statistically insignificant ($p > 0.05$) (Table 11.1., Figure 26.).

Table 11.1. Mean and standard deviation pressure values on upper central incisor during rest and swallowing in control group.

Control Group	U1 (R)	U1 (S)
Beginning	19,5±14,95	148,53±23,09
10th month	16,93±3,46	143,4±26,74
12th month	19,1±3,79	150,37±28,1
Fr	1,82	0,35
P	0,429	0,959

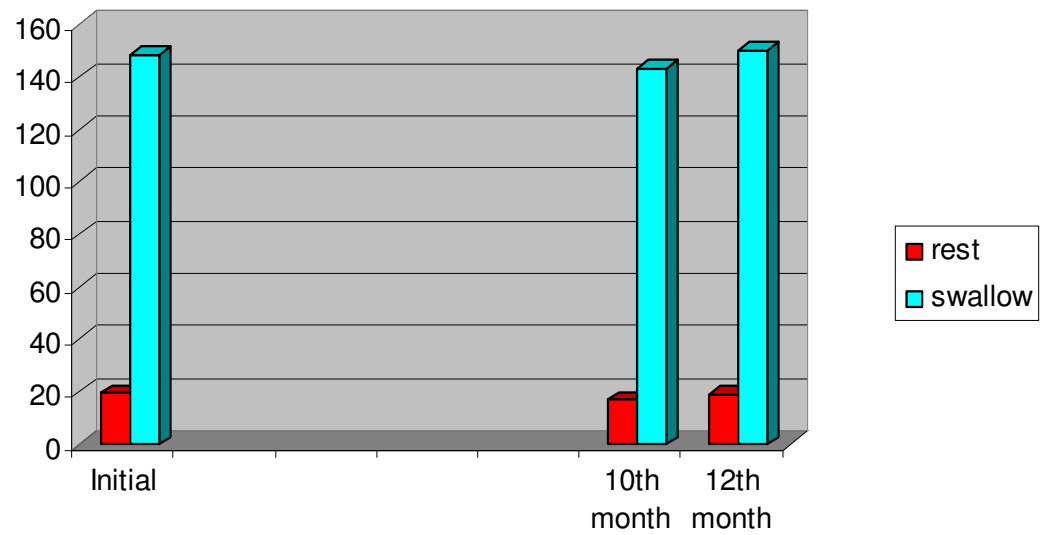


Figure 26. Graph displaying tongue pressure changes in gr/cm^2 , acting on upper central incisor during rest and swallowing in control group.

6.5.2.3. Pressure Changes during Pronunciation

The initial average tongue pressure value for the pronunciation of the word ‘pasta’ was $33,67 \pm 14,37$ gr/cm². At the 10th month and 12th month, the average pressure values were $29,77 \pm 7,08$ gr/cm² and $28,97 \pm 1,84$ gr/cm² respectively. The differences between all the measurement times were statistically insignificant ($p > 0.05$).

The initial average tongue pressure value for the pronunciation of the word ‘çiçek’ was $28,07 \pm 7,49$ gr/cm². At the 10th month and 12th month, the average pressure values were $25,77 \pm 3,95$ gr/cm² and $28,58 \pm 4,64$ gr/cm² respectively. The differences between all the measurement times were statistically insignificant ($p > 0.05$).

The initial average tongue pressure value for the pronunciation of the word ‘dede’ was $35,23 \pm 6,49$ gr/cm². At the 10th month and 12th month, the average pressure values were $26,87 \pm 7,42$ gr/cm² and $27,53 \pm 6,63$ gr/cm² respectively. The decrease between beginning, 10th month and 12th month values were statistically insignificant ($p > 0.05$).

The initial average tongue pressure value for the pronunciation of the word ‘katı’ was $30,87 \pm 6,92$ gr/cm². At the 10th and 12th month, the average pressure values were $29,07 \pm 8,56$ gr/cm² and $28,97 \pm 8,96$ gr/cm² respectively. The differences between all measurement times were statistically insignificant ($p > 0.05$) (Table 11.2., Figure 27.).

Table 11.2. Pressure values acting on upper central incisor during pronunciation in control group.

	Pasta	Çiçek	Dede	Katı
Beginning	33,67±14,37	28,07±7,49	35,23±6,49	30,87±6,92
10th month	29,77±7,08	25,77±3,95	26,87±7,42	29,07±8,56
12th month	28,97±1,84	28,58±4,64	27,53±6,63	28,97±8,96
Fr	3	2,56	4,33	0,33
P	0,252	0,249	0,141	0,956

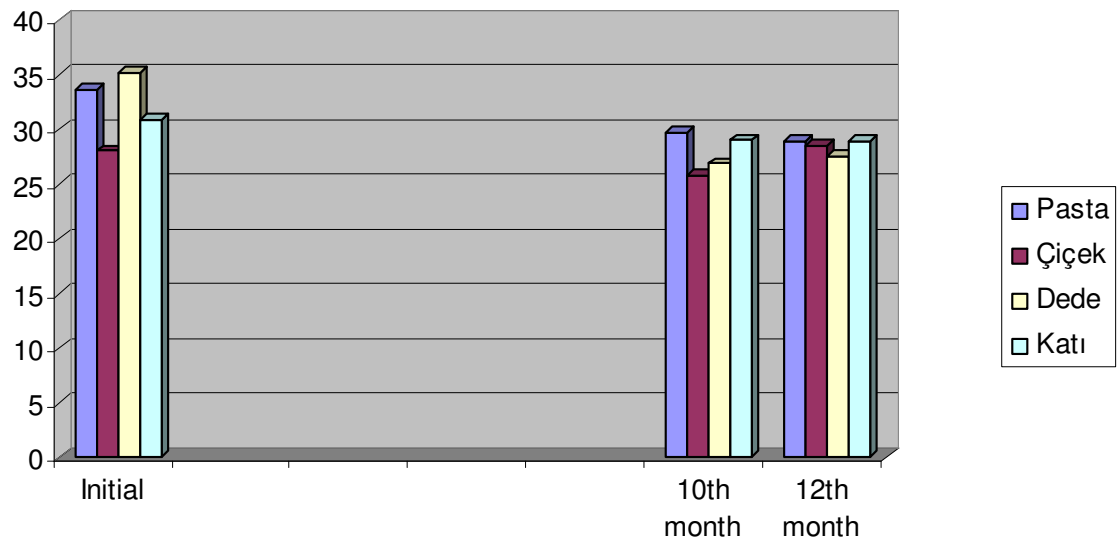


Figure 27. Graph displaying tongue pressure changes in gr/cm^2 , acting on upper central incisor during pronunciation, in control group.

6.5.3. Pressure Changes on Lower Central Incisor

6.5.3.1. Pressure Changes in Rest Position

The average resting pressure on the lingual side of lower central incisor in the beginning was measured as $16,6 \pm 3,71 \text{ gr/cm}^2$. The average resting pressures at the 10th month and 12th month were $16,2 \pm 4,83 \text{ gr/cm}^2$ and $14,87 \pm 3,74 \text{ gr/cm}^2$ respectively. The differences between the beginning, 10th month and 12th month values were statistically insignificant ($p > 0.05$) (Table 12., Figure 28.).

6.5.3.2. Pressure Changes during Swallowing

The average swallowing pressure on the lingual side of lower central incisor at the beginning was measured as $131,97 \pm 22,04 \text{ gr/cm}^2$. The average resting pressures at the 10th month and 12th month were $132,87 \pm 9,61 \text{ gr/cm}^2$ and $131,3 \pm 15,13 \text{ gr/cm}^2$ respectively. The differences between the beginning, 10th month and 12th month values were statistically insignificant ($p > 0.05$) (Table 12., Figure 28.).

Table 12. . Mean and standard deviation pressure values on lower central incisor during rest and swallowing in control group.

	L1 (R)	L1 (S)
Beginning	16,6±3,71	131,97±22,04
10th month	16,2±4,83	132,87±9,61
12th month	14,87±3,74	131,3±15,13
Fr	1,65	0,33
P	0,429	0,956

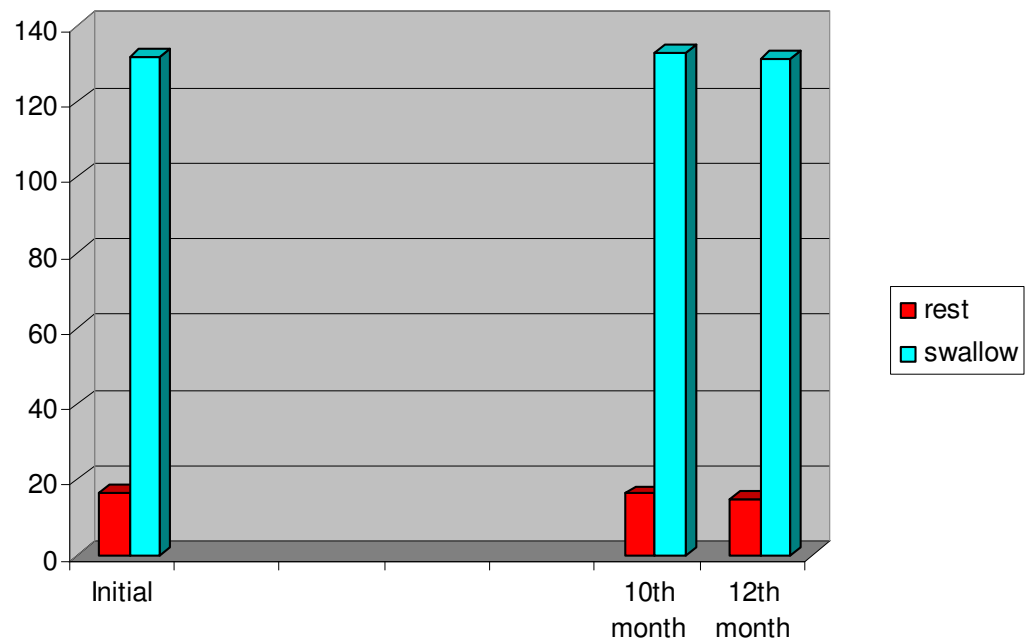


Figure 28. Graph displaying pressure values in gr/cm^2 , acting on lower incisor, during rest and swallowing, in control group.

6.6. Comparison between Average Pressure Findings in Study and Control Group

6.6.1. Evaluation of Average Pressure Findings on Upper First Molar

The average pressure findings for upper first molar during rest position and swallowing both in the study and control group are compared by Mann Whitney-U test and are shown in Table 16. The difference between the rest position pressures are statistically insignificant ($p>0.05$). At the 10th month, the average resting tongue pressure in the study group was measured as $12\pm3,65$ gr/cm² while it was measured as $19,9\pm6,47$ gr/cm² in the control group. At the 12th month, the average resting tongue pressure in the study group was measured as $12,57\pm3,65$ gr/cm² while it was measured as $19,13\pm5,81$ gr/cm² in the control group. The difference between the study and the control group for average resting pressures, at the 10th and 12th months were statistically significant ($p<0.05$).

The difference between the study and the control group for average swallowing pressures, at the beginning, 10th and 12th months were statistically insignificant ($p>0.05$) (Table 13., Figure 29.a.,b.).

Table 13. Mean and standard deviation resting and swallowing pressure values for upper first molar in study and control group.

	Study Group	Control Group	MW	P
U6(R) Beginning	16,66±6,37	18,97±4,92	25	0,219
U6(R) 10 th month	12±3,65	19,9±6,47	9,5	0,007
U6(R) 12 th month	12,57±3,65	19,13±5,81	14	0,029
U6(S) Beginning	149,86±28,28	166,7±26,47	30,5	0,456
U6(S) 10 th month	135,42±18,17	142,47±14,12	28	0,368
U6(S) 12 th month	150,68±20,88	143,73±15,86	32	0,579

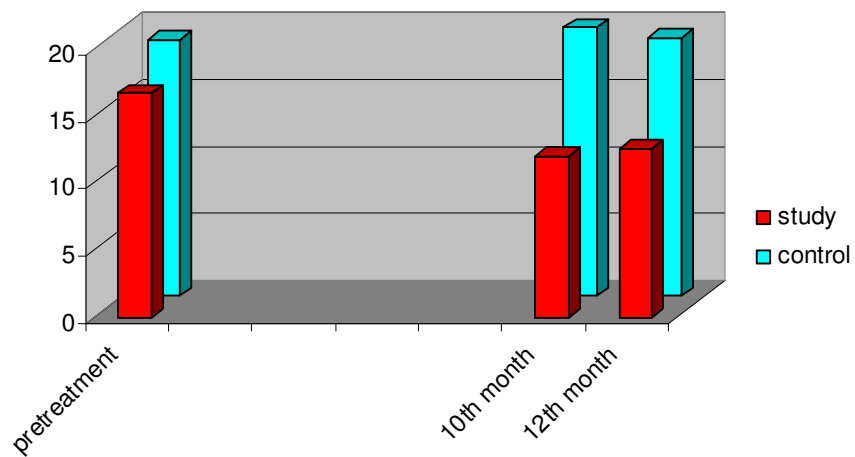


Figure 29.a. Graph comparing resting tongue pressures acting on upper first molar in gr/cm^2 , between study and control group.

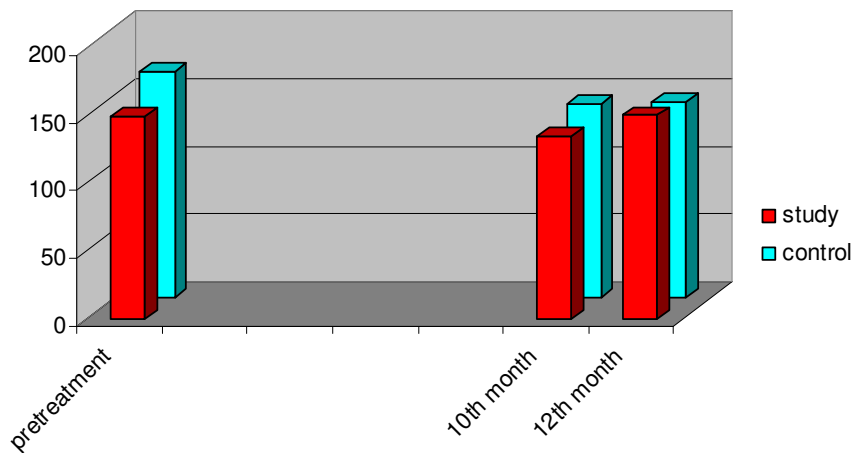


Figure 29.b. Graph comparing swallowing tongue pressures acting on upper first molar in gr/cm^2 , between study and control group.

6.6.2. Evaluation of Average Pressure Findings on Upper Central Incisor

The average pressure findings for upper central incisor during rest position and swallowing both in the study and control group were compared by Mann Whitney-U test and are shown in Table 14. The average resting pressure value in the beginning in the study and control groups were measured as $16,42 \pm 8,95 \text{ gr/cm}^2$ and $19,5 \pm 14,95 \text{ gr/cm}^2$ respectively ($p > 0.05$). At the 10th month the average resting pressure values showed a slight decrease in both groups and were measured as $13,31 \pm 2,46 \text{ gr/cm}^2$ and $16,93 \pm 3,46 \text{ gr/cm}^2$ respectively in study and control group ($p > 0.05$). At the 12th month the average resting pressure value in the study group kept on decreasing and was measured as $11,63 \pm 4,7 \text{ gr/cm}^2$ while it remained quite the same in the control group with an average of $19,1 \pm 3,79 \text{ gr/cm}^2$. The difference between two groups for average resting pressure at the 12th month was statistically significant ($p < 0.05$).

The difference between study and control group for average swallowing pressures at the beginning, 10th and 12th month were statistically insignificant ($p > 0.05$) (Table 14, Figure 30.a.,b.)

Table 14. The average resting and swallowing tongue pressure values for upper central incisor in study and control group.

	Study Group	Control Group	MW	P
U1(R) Beginning	16,42±8,95	19,5±14,95	38,5	0,965
U1(R) 10 th month	13,31±2,46	16,93±3,46	17	0,053
U1(R) 12 th month	11,63±4,7	19,1±3,79	7	0,005
U1 (S) Beginning	154,12±41,12	148,53±23,09	39	0,998
U1 (S) 10 th month	128,59±16,78	143,4±26,74	25,5	0,236
U1 (S) 12 th month	136,82±17,42	150,37±28,1	26,5	0,273

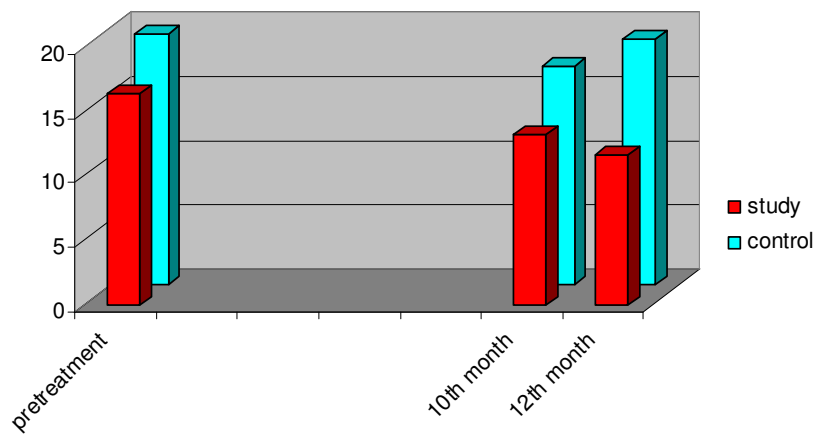


Figure 30.a. Graph comparing resting tongue pressures acting on upper central incisor in gr/cm², between study and control group.

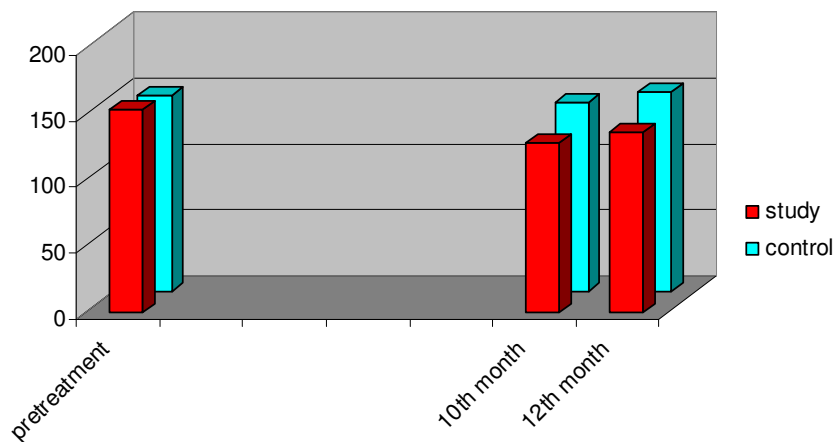


Figure 30.b. Graph comparing swallowing tongue pressures acting on upper central incisor in gr/cm², between study and control group.

6.6.2.1. Evaluation of Average Pressure Findings during Pronunciation

The average pressure findings for upper central incisor during pronunciation both in the study and control group were compared by Mann Whitney-U test and they are shown in Table 15.

The average tongue pressure value during pronunciation of the word ‘pasta’ was measured as $31,75 \pm 12,68 \text{ gr/cm}^2$ in study group and $33,67 \pm 14,37 \text{ gr/cm}^2$ in control group ($p > 0.05$). At the 10th month this value decreased to $22,15 \pm 5,21 \text{ gr/cm}^2$ in study group and $29,77 \pm 7,08 \text{ gr/cm}^2$ in control group. At the 12th month, the values were quite the same as in the 10th month, to be $23,79 \pm 5,74 \text{ gr/cm}^2$ in study group and $28,97 \pm 1,84 \text{ gr/cm}^2$ in control group. The difference between the study and the control group in both 10th and 12th month values were statistically significant ($p < 0.05$).

The average tongue pressure value during the pronunciation of the word ‘çiçek’ at the beginning was measured as $31,28 \pm 6,35 \text{ gr/cm}^2$ in study group and $28,07 \pm 7,49 \text{ gr/cm}^2$ in control group ($p > 0.05$). At the 10th month, the average value was $22,25 \pm 7,37 \text{ gr/cm}^2$ and $25,77 \pm 3,95 \text{ gr/cm}^2$ for study and control group respectively. At the 12th month the average pressure value was measured as $23,88 \pm 3,61 \text{ gr/cm}^2$ for the study group and $28,58 \pm 4,64 \text{ gr/cm}^2$ for the control group. The difference between the study and control group at the 12th month was statistically significant ($p < 0.05$).

The average tongue pressure values for the pronunciation of the words ‘dede’ and ‘katı’ are also shown in Table 15. The average tongue pressure values during pronunciation show a continuous decrease from the beginning to 12th month in both groups and the difference between the study and control group during the pronunciation of these words was statistically insignificant for all the measurement times ($p > 0.05$).

Table 15. The average tongue pressure values during pronunciation in study and control group.

		Study Group	Control Group	MW	P
Pasta	Beginning	31,75±12,68	33,67±14,37	34	0,661
Pasta	10 th month	22,15±5,21	29,77±7,08	12	0,018
Pasta	12 th month	23,79±5,74	28,97±1,84	16	0,044
Çiçek	Beginning	31,28±6,35	28,07±7,49	29	0,38
Çiçek	10 th month	22,25±7,37	25,77±3,95	29	0,38
Çiçek	12 th month	23,88±3,61	28,58±4,64	15	0,035
Dede	Beginning	32,37±9,14	35,23±6,49	30	0,43
Dede	10 th month	22,91±6,17	26,87±7,42	31	0,483
Dede	12 th month	24±6,9	27,53±6,63	26	0,254
Katı	Beginning	30,72±13,75	30,87±6,92	29	0,38
Katı	10 th month	23,31±7,66	29,07±8,56	18	0,066
Katı	12 th month	23,28±6,15	28,97±8,96	23,5	0,173

6.6.3. Evaluation of Average Pressure Findings on Lower Central Incisor

The average pressure findings for lower central incisor during rest and swallowing both in the study and control group were compared by Mann Whitney-U test and are shown in Table 16.

The average resting pressures for lower incisor in the study group were measured as 15,26±5,27 gr/cm², 11,83±2,98 gr/cm² and 11,91±4,85 gr/cm² at the beginning, 10th month and 12th month respectively. The average resting pressures for the control group were 16,6±3,71 gr/cm², 16,2±4,83 gr/cm² and 14,87±3,74 gr/cm² at the beginning, 10th month and 12th month respectively. The differences between the study and control group for the resting values measured at all times were statistically insignificant (p>0.05).

The average swallowing pressures for lower incisor in the study group were measured as 138,25±29,57 gr/cm², 129,82±20,36 gr/cm² and 138,08±16,56 gr/cm² at the beginning, 10th month and 12th month respectively. The average swallowing pressures for the control group were 131,97±22,04 gr/cm², 132,87±9,61 gr/cm² and

131,3±15,13 gr/cm² at the beginning, 10th month and 12th month respectively. The differences between the study and control group for the swallowing values measured at all times were statistically insignificant ($p>0.05$) (Table 16., Figure 31.a.,b.).

Table 16. The average resting and swallowing tongue pressure values for lower central incisor in study and control group.

	Study Group	Control Group	MW	p
L1 (R) Beginning	15,26±5,27	16,6±3,71	30	0,43
L1 (R) 10 th month	11,83±2,98	16,2±4,83	17	0,054
L1 (R) 12 th month	11,91±4,85	14,87±3,74	25	0,219
L1 (S) Beginning	138,25±29,57	131,97±22,04	38	0,93
L1 (S) 10 th month	129,82±20,36	132,87±9,61	29,5	0,405
L1 (S) 12 th month	138,08±16,56	131,3±15,13	29,5	0,405

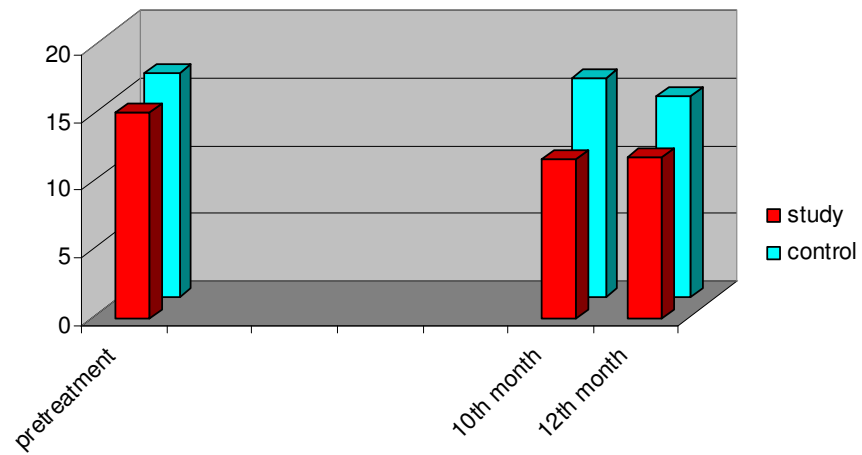


Figure 31.a. Graph comparing resting tongue pressures acting on lower central incisor in gr/cm², between study and control group.

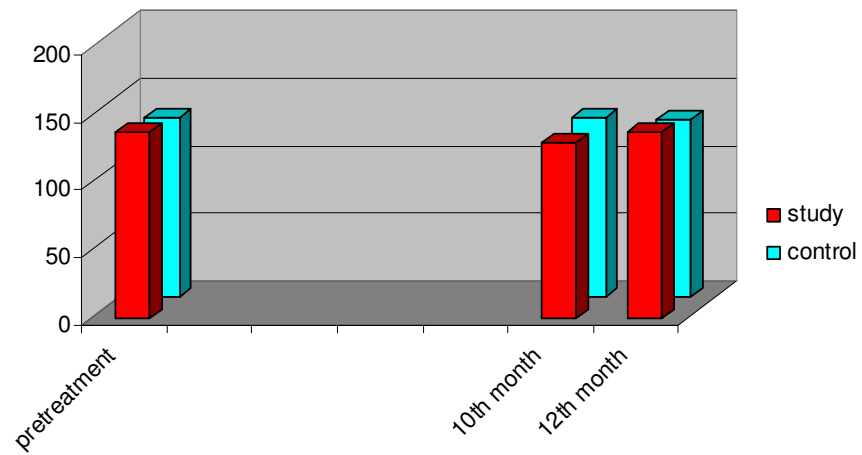


Figure 31.b. Graph comparing swallowing tongue pressures acting on lower central incisor in gr/cm², between study and control group.

6.7. Postero-Anterior and Lateral Cephalometric Evaluation

Postero-anterior and lateral cephalometric x-rays of the study group were taken before the insertion of the crib appliance and right after the removal of the crib appliance at the 10th month. Postero-anterior and lateral cephalometric x-rays of the control group were also taken at the beginning and at the 10th month corresponding to the crib appliance removal time in the study group. The angular and linear measurements at the beginning and at the end for each group were evaluated by Wilcoxon test separately. The beginning values and 10th month values for both groups were compared by Mann-Whitney-U test (Table 17.,18.).

6.7.1. Angular Measurements in Study Group

According to the evaluations; the changes in SNA, SNB, IMPA, and IIA angles were statistically significant ($p < 0.05$) (Table 17.).

6.7.2. Angular Measurements in Control Group

According to the initial and 10th month tracings, changes in angular parameters were insignificant in control group ($p > 0.05$) (Table 17).

Table 17. Mean and standard deviation values for angular evaluations measurements in study and control group.

		Study Group	Control Group	MW	p
SNA	Beginning	78,73±3,91	80,08±4,36	33	0,598
	10th month	79,81±3,72	80,83±4,38	35	0,725
	Z	-2,54	-1,84		
	P	0,011	0,066		
SNB	Beginning	73,54±4,37	73,17±4,75	36,5	0,825
	10th month	74,85±3,14	74±4,94	35,5	0,758
	Z	-2,26	-1,63		
	P	0,024	0,102		
ANB	Beginning	5,27±1,39	7,08±2,2	20	0,089
	10th month	4,96±1,7	7±2,41	21	0,113
	Z	-0,45	-0,38		
	P	0,656	0,705		

SN/MP	Beginning	43,35±6,27	44,83±5	34	0,66
	10 th month	42,58±5,27	44±5,69	32,5	0,563
	Z	-0,98	-0,14		
	P	0,325	0,892		
SN/PP	Beginning	9,15±3,05	9,33±3,08	37	0,859
	10 th month	9,38±2,62	9,17±4,88	34	0,657
	Z	-0,16	0,00		
	P	0,873	1		
U1/PP	Beginning	117,46±6,8	115,33±10,61	33	0,598
	10 th month	117,58±4,93	118,33±8,21	36	0,792
	Z	-0,32	-1,63		
	P	0,752	0,104		
U1/SN	Beginning	107,81±6,55	105,25±7,03	27,5	0,311
	10 th month	107,54±5,42	107,75±4,92	37	0,859
	Z	-0,12	-1,26		
	P	0,905	0,207		
IMPA	Beginning	93,08±6,66	94,17±5,64	34	0,66
	10 th month	91,27±8,38	93,08±5,31	29,5	0,403
	Z	-2,20	-0,73		
	P	0,028	0,465		
IIA	Beginning	116,62±7,64	117,42±13,48	37	0,861
	10 th month	120,46±8	114,67±10,73	24	0,188
	Z	-2,17	-0,81		
	P	0,03	0,416		
NLA	Beginning	110,46±9,18	117,42±9,4	21,5	0,124
	10 th month	111,54±7,78	116±10,43	27,5	0,313
	Z	-0,39	-1,76		
	P	0,694	0,078		
URMA	Beginning	60±13,29	61,33±11,09	38	0,93
	10 th month	55,5±13,03	60,67±13,29	28,5	0,357
	Z	-1,54	-0,53		
	P	0,124	0,596		
ULMA	Beginning	63,46±11,45	60±13,18	34	0,661
	10 th month	58,88±7,85	59,5±10,56	36	0,792
	Z	-1,89	-0,53		
	P	0,059	0,598		
LRMA	Beginning	39,89±8,87	46,42±11,78	27,5	0,313
	10 th month	42,69±11,5	46,17±11,36	28	0,334
	Z	-1,40	-0,27		
	P	0,162	0,786		
LLMA	Beginning	40±8,19	43,33±9,18	36,5	0,826
	10 th month	42,81±9,72	42,67±8,73	38	0,93
	Z	-1,85	-0,96		
	P	0,065	0,336		

6.7.3. Linear Measurements in Study Group

According to the linear evaluations; changes in OB, UIT-X, UIT-PP, LIT-MP, UMT-PP, UMT-X, UMT-Y, LMT-GM, LMT-Y, ANS-Me, N-Me, S-Go, UIMW and Jarabak values were statistically significant ($p<0.05$) (Table 18.).

6.7.4. Linear Measurements in Control Group

According to the evaluations; changes in LMT-Y and N-Me values were statistically significant ($p<0.05$) (Table 18.).

6.7.5. Evaluation of Changes in Lateral Cephalometric and Postero-Anterior X-ray Values in Study and Control Group

According to the evaluations for all parameters, the amount of change in interincisal angle (IIA) was $-3,85\pm5,92$ for study group, which means an increase. The amount of change in study group was $2,75\pm5,53$, which means a decrease. The difference between the amount of change in study and control group was statistically significant ($p= 0,048$). The amount of change in UIT-X value was $-2,54\pm1,82$ for study group, and $-0,42\pm1,66$ for control group. The difference was statistically significant ($p=0,02$). The amount of change in S-Go value in study group was $-2,81\pm2,24$, and $-0,83\pm1,17$ in control group ($p=0,033$). Similarly, the amount of change in Jarabak value was $-1,02\pm1,36$ in study group, and $0,45\pm1,31$ in control group ($p= 0,043$) (Table 19.).

Table 18. Mean and standard deviation values for linear measurements in study and control group.

		Study Group	Control Group	MW	P
OB	Beginning	-2,12±1,12	-2,83±2,07	33,5	0,613
	10 th month	0,62±2,08	-2,33±2,75	14,5	0,031
	Z	-2,85	-0,53		
	P	0,004	0,599		
OJ	Beginning	5,65±1,92	6,08±2,85	35	0,724
	10 th month	6,09±2,27	6,42±3,02	37,5	0,895
	Z	-0,87	-1,00		
	P	0,387	0,317		
UIT-X	Beginning	70,46±5,14	69,33±3,6	36	0,792
	10 th month	73±4,79	69,75±4,51	24	0,187
	Z	-3,09	-0,68		
	P	0,002	0,496		
UIT-PP	Beginning	27,77±3,4	26,5±3,44	32,5	0,568
	10 th month	29,27±2,59	26,5±2,83	17,5	0,057
	Z	-2,57	-0,11		
	P	0,01	0,915		
LIT-X	Beginning	72,19±5,07	71,83±3,53	32,5	0,567
	10 th month	72,5±6,08	72,33±4,68	38	0,93
	Z	-0,58	-0,54		
	P	0,56	0,588		
LIT-MP	Beginning	40,19±3,39	39,5±3,33	35,5	0,758
	10 th month	41,23±3,51	40,92±2,69	37,5	0,895
	Z	-2,69	-1,63		
	P	0,007	0,102		
UMT-PP	Beginning	20,85±1,55	21,08±1,69	33	0,592
	10 th month	21,73±1,95	21,67±2,16	38,5	0,965
	Z	-2,51	-1,08		
	P	0,012	0,279		
UMT-X	Beginning	62,42±3,52	62,42±3,29	38	0,93
	10 th month	64,27±4,17	62,83±3,11	31	0,48
	Z	-2,84	-0,67		
	P	0,005	0,5		
UMT-Y	Beginning	30,54±5,87	33±4,9	27,5	0,312
	10 th month	33,19±5,64	35,17±6,27	31	0,482
	Z	-3,07	-1,83		
	P	0,002	0,068		
LMT-GM	Beginning	29,88±2,69	29,67±1,78	36,5	0,823
	10 th month	31,27±2,99	30,17±1,69	28,5	0,353
	Z	-2,86	-0,92		
	P	0,004	0,357		

LMT-X	Beginning	64,54±3,47	63,17±3,19	29	0,377
	10 th month	65,62±4,28	64±3,35	32,5	0,566
	Z	-1,53	-0,95		
	P	0,125	0,343		
LMT-Y	Beginning	32,31±6,28	32,92±4,78	32,5	0,566
	10 th month	34,54±5,08	36±6,48	31	0,482
	Z	-3,07	-2,03		
	P	0,002	0,042		
ANS-ME	Beginning	65,38±4,95	63,33±3,56	29	0,379
	10 th month	66,81±5,03	64,42±3,95	24,5	0,202
	Z	-2,01	-1,24		
	P	0,045	0,216		
N-ME	Beginning	117,23±7,25	115±4,27	34,5	0,693
	10 th month	121,27±9,42	116,92±4,4	30,5	0,456
	Z	-3,06	-2,06		
	P	0,002	0,039		
S-Go	Beginning	69,88±4,22	67,67±1,97	24	0,186
	10 th month	72,69±4,12	68,5±1,87	13,5	0,025
	Z	-3,02	-1,63		
	P	0,003	0,102		
UIMW	Beginning	56,42±3,16	54,17±2,64	20,5	0,102
	10 th month	54,04±3,63	52,33±3,93	25	0,217
	Z	-2,60	-1,63		
	P	0,009	0,102		
LIMW	Beginning	50±2,88	50,17±3,54	38,5	0,965
	10 th month	50,38±3,01	48,67±2,94	26	0,25
	Z	-1,37	-1,29		
	P	0,17	0,197		
ANSMe/NMe	Beginning	55,69±1,84	55,03±2,16	26	0,254
	10 th month	55,03±1,89	55,12±3,04	38	0,93
	Z	-1,16	-0,94		
	P	0,248	0,345		
Jarabak	Beginning	58,7±3,69	58,2±2,86	38,5	0,965
	10 th month	59,72±3,39	57,75±2,86	29	0,38
	Z	-2,38	-0,95		
	P	0,017	0,344		

Table 19. Comparison between the changes in lateral cephalometric and postero-anterior x-ray values in study and control group.

	Study Group	Control Group	MW	p
SNA	-1,08±1,17	-0,75±0,94	33,5	0,619
SNB	-1,31±1,79	-0,83±1,17	34,5	0,685
ANB	0,31±1,91	0,08±0,59	37,5	0,894
SN/MP	0,77±2,64	0,83±3,31	36,5	0,826
SN/PP	-0,23±1,73	0,17±2,93	35,5	0,756
UI/PP	-0,12±5,32	-3±3,58	26,5	0,271
UI/SN	0,27±4,88	-2,5±3,9	29	0,378
IMPA	1,81±6,11	1,08±4,01	27	0,291
IIA	-3,85±5,92	2,75±5,53	16,5	0,048
NLA	-1,08±7,47	1,42±1,56	29	0,379
OB	-2,73±2,04	-0,5±1,92	18	0,064
OJ	-0,43±2,23	-0,33±0,75	35,5	0,758
UIT-X	-2,54±1,82	-0,42±1,66	13	0,02
UIT-PP	-1,5±1,68	0±1,23	20,5	0,098
LIT-X	-0,31±1,65	-0,5±2,86	38,5	0,965
LIT-MP	-1,04±1,11	-1,42±1,69	33,5	0,621
UMT-PP	-0,88±0,98	-0,58±1,24	35	0,723
UMT-X	-1,85±1,81	-0,42±2,13	26,5	0,268
UMT-Y	-2,65±1,99	-2,17±2,64	31	0,478
LMT-GM	-1,38±1,19	-0,5±1,26	25,5	0,229
LMT-X	-1,08±2,3	-0,83±2,93	38,5	0,965
LMT-Y	-2,23±2,15	-3,08±2,38	30,5	0,452
ANS-ME	-1,42±2,21	-1,08±1,8	33	0,596
N-ME	-4,04±4,18	-1,92±1,36	27	0,289
ANSMe/Nme	0,66±1,7	-0,08±1,5	27,5	0,311
S-Go	-2,81±2,24	-0,83±1,17	15	0,033
Jarabak	-1,02±1,36	0,45±1,31	16	0,043
UIMW	2,38±2,46	1,83±2,48	32	0,535
LIMW	-0,38±1,06	1,5±2,43	18,5	0,064
URMA	4,5±9,81	0,67±2,66	25,5	0,236
ULMA	4,58±7,53	0,5±2,88	17,5	0,059
LRMA	-2,81±6,06	0,25±2,32	28	0,334
LLMA	-2,81±5,06	0,67±1,63	20	0,094

7. DISCUSSION

7.1. Discussion of Aim

Anterior open bite malocclusion is considered one of the most difficult problems to treat by any means. Proper diagnosis, successful treatment, and long-term retention of open bite malocclusion have been considered main subject of discussions in most studies. There have been numerous theories proposed for the cause of this malocclusion including inherited facial form, unfavorable growth pattern, digital habits, posture, nasopharyngeal airway obstruction and tongue posture and function. Several aspects of function together with posture and environmental influences interact with facial morphology to produce open bite in some patients (78).

The opinion that ‘the position of the teeth on the alveolar bone is determined by surrounding muscles and soft tissues’ was firstly stated by Tomes (155). Dentition and alveolar bone are constantly under pressure from tongue, lips and cheeks during functions like speech, chewing and swallowing. Pressure is defined as force (N) per unit area (m^2). As the soft tissues surrounding the facial skeleton apply forces on alveolar bone and teeth from multiple directions, these functional forces acting on the facial skeleton may well be defined as pressure. (91,154). In 1911, E. H. Angle (6) had a new theory about function acting on development. He stated that if the teeth are well aligned and occlusal relationships are good, then there is a normal function. In addition, the stimulation of this normal functioning system leads to an ideal facial development. S.J. Kloehe (82) carried out a study in 1953 and concluded that there was a force equilibrium to hold the teeth in place in a normal occlusion, and that dental arches were supported by the tongue from inside and by the lips from outside. As a result, a characteristic occlusion for each individual is established.

Balance of forces between perioral musculature and tongue cannot be described as a simple one-to-one relationship. Tongue has been shown to exert greater force on the dentition than the perioral muscles. Other factors such as the periodontium and alveolar bone support must be considered in evaluations of muscular balance. The duration of force, because of the biologic response, is more important than its magnitude. During mastication, not only do the teeth move slightly, but also the alveolar bone and basal bone of maxilla and mandible bend and flex. These changes

occur in a matter of seconds, and the teeth and jaws are restored to their original positions as quickly as they were displaced (49, 118, 139). In contrast to forces from mastication, light sustained pressures from lips, cheeks and tongue at rest are important determinants of tooth position. Even very light forces are successful in moving teeth, if the force is of long enough duration. The duration threshold seems to be approximately 6 hours in humans. Since the light pressures from lips, cheeks, and tongue at rest position are maintained most of the time, these soft tissue pressures should affect tooth position. It seems unlikely; however, that the intermittent short-duration pressures created when the tongue and lips contact the teeth during swallowing or speaking would have any significant impact on tooth position. As with the masticatory forces, the pressure magnitudes would be great enough to move a tooth, but the duration is inadequate (117, 120, 124, 151, 153, 156).

To date, various studies have been performed on assessing cheek, tongue and lip pressures during resting, swallowing, mastication and speech. In 1985, Thüer, Janson and Ingervall (153) measured the forces from the lips on the teeth in children with normal incisor relationship and evaluated electromyographic lip muscle activity using an extra oral pressure transducer incorporated in a water filled fluid system with an intraoral mouthpiece. They reported that lip pressures at rest and during chewing and swallowing appear to be of different character, the former being dependent on lip tonicity, the latter on muscle activity. The lip pressures in chewing and swallowing were correlated with the morphology of the dentition, and this was considered to be an adaptative behaviour but they did not measure tongue pressures acting on the dentition.

In 1990, Lindeman and Moore (91) carried out a study on measurements of intraoral muscle force with foil strain gauges, load cells, and pressure transducers bonded to a stent and to a lip bumper in 5 adults with normal incisor and molar relationships. They measured pressures by different types of measuring devices, during swallowing, pronunciation, chewing, sucking and blowing on a straw but they did not apply this study on growing subjects.

In 1989, Lubit and Wallach (94) used a pneumohydraulic capillary infusion system in order to evaluate the tonic and peak lip pressures. Thüer and Ingervall (41,42, 151,153) used the same method for measurement of pressure from the tongue on the teeth in young adults and children with clinically normal occlusion in 1985, in 1991, in

1992 and 1999. Using the same extra-oral measuring system, Fröhlich et al (40) investigated influence of surgical tongue reduction on pressure of the tongue on the teeth in 21 children and adolescents with ages ranging from 9 years 7 months to 19 years 5 months. They reported that surgical procedure tended to 'normalize' the pressure but the effect was small and not significant. Investigating the influence of the procedure in growing individuals was needed in order to evaluate the adaptive behavior for a longer period.

In 2002, Cheng et al (19) investigated the relationship between tongue function during swallowing and dentofacial morphology using computer-aided B+M mode of ultrasonography combined with cushion-scanning technique (CST) in healthy adult volunteers. They reported that there were significant correlations between tongue movement during swallowing and dentofacial morphology.

In 2003, Küçükkeleş and Ceylanoğlu (85) evaluated the changes in lip, cheek and tongue pressures after rapid maxillary expansion using an EPL BO diaphragm pressure transducer connected to a digital strain indicator. Their study group consisted of 12 subjects (seven girls, five boys) whose ages ranged between 13 and 20. They reported that the cheeks and the lips almost adapted to the new position of dental arches whereas the tongue adaptation took comparatively longer. A year later, completing his study with 28 patients, Ceylanoğlu (18) reported that minimum 6 months of retention period was needed in order to obtain intraoral pressure equilibrium again, after expansion.

In 2005, Ruan et al (124) studied the muscular forces exerted on the deciduous dentition and the relationship between the muscular forces, sex, and oral function. Their study was based on 39 children with a mean age of 4.96 years, ranging from 3.7 to 6.0 years with normal molar and incisor relationships. They reported that the deciduous teeth were not in a state of absolute balance between external and internal forces; the distributing manner and unbalanced mode of the forces were different with different oral functions.

Several treatment modalities have been used to correct anterior open bites by preventing the placement of the tongue tip between anterior teeth. The tongue crib is an appliance that is designed to modify tongue behavior or to break habits, or both. Some authors (33, 39, 58, 59) have reported that crib is a successful treatment tool, whereas

others (32,146) have reported the opposite. The main reason for this controversy may be the individual variations in the adaptive capability of the tongue to the new environment created by the appliance.

In orthodontics, appliances such as tongue cribs are often applied with only consideration for the tongue tip position and, the tongue's function during deglutition is often overlooked. (43,126). It has been reported that tongue thrust swallowing was a physiologic adaptation to achieve anterior seal in patients with anterior open bite (21, 43, 114, 145, 146, 147). Proffit (114) suggested that correcting the tooth positions in open bite cases should cause a change in swallowing patterns. If the anterior seal function of the tongue is prevented by restricting its forward movement by means of a tongue crib, the alterations in swallowing pattern should be investigated. In this manner, Cleall (21) carried out a study on tongue movements using cinefluorography in patients wearing palatal crib. He reported that palatal crib forced the tongue to function in a more posterior and higher position, however; he presented no statistical data confirming this statement.

The tongue affects the dentition and the alveolar bone during mastication, deglutition, speech and at rest. Kincaid (79) reported that the average frequency of deglutition was 1600 times a day, and Straub (143) stated that it was about 2400 times a day. Therefore, one could conclude that the tongue can deliver orthodontic forces with considerable frequency.

Sayin et al. (126) carried out a study on initial effects of the tongue crib on tongue movements during deglutition by means of magnetic resonance imaging. Study group consisted of 11 patients with a mean age of 11.09 ± 2.02 years and a mean overbite of -5.14 ± 1.83 mm. The control group consisted of 10 subjects with a mean age of 14.5 ± 2.6 years and a mean overbite of 1.6 ± 0.5 mm. Open bite group was instructed to wear palatal cribs at least 18 hours a day for 2 weeks to ensure adaptation and were recalled for examination. They stated that tongue tip was positioned more posteriorly when the crib was in place during deglutition and to compensate for the posterior position of the tongue's tip (caused by tongue crib), adaptive changes occurred in the anterior and mid portions of the tongue's dorsum.

Cleall (21) suggested that the glossopharyngeal structures at rest and during swallowing adapted well to changes in sensory stimuli created by the insertion of the

tongue crib. He also reported that the tongue crib restricted the forward movement of the tongue and influenced the tongue tip to function more posteriorly during deglutition. Similarly Sayin et al (126) suggested that the tongue and other structures acting in deglutition immediately adapt to changes in the local environment created by tongue crib and propel the bolus while protecting the airway patency. They also stated that the tongue tip should be displaced posteriorly and inferiorly to accommodate tongue crib. However, further studies are needed to investigate whether or not these compensatory changes were maintained after the correction of open bite.

Yashiro et al (173) treated an adult patient with anterior open bite and tongue thrust swallow, by means of premolar extractions and palatal crib wear for 7 months. After the treatment, significant adaptation was observed in electromyographic activity of genioglossus muscle during swallowing. However, the same result was not observed during chewing. They concluded that the motor output to the tongue could not be altered easily in adults by changing the occlusal relationships.

Haryett (58,59) studied the effectiveness of crib appliances in patients with thumb sucking habits and reported that cribs were very effective in stopping the habit when worn for 10 months. Half of his sample was less than 6 years old.

Justus (72) reported that tongue cribs were effective in closing the open bites when worn for one year. He also stated that using cribs with sharp spurs is recommended in open bite cases related to anterior tongue posture.

Subtelny and Sakuda (146) evaluated a sample of eight open bite patients with mean ages greater than 12 years old who wore tongue cribs for 6 months. They reported no closure of open bite during that time.

Epker and Fisch (32) stated that cribs were usually not effective for treating open bites except in growing patients with Class I occlusion, good facial esthetics, and lip competence. However, they did not give any statistical data to substantiate their statements.

Huang et al (64) carried out a study on stability of anterior open bite treated with crib therapy on 33 open bite patients. The length of crib use varied between 5 to 40 months. The study group consisted of growing and nongrowing patients. They reported small number of relapse patients and suggested that, the crib improves stability and the reason for this increased stability may be due to a modification of tongue position or

posture. However, the pressure acting on the dentition created by the tongue was not evaluated.

Pedrin et al (108) carried out a study to see the treatment effects of a removable appliance with palatal crib combined with high-pull chin cup therapy in open bite patients. Their treatment lasted 12 months and they reported dentoalveolar changes.

In 2003, Peng et al. (110) carried out a study on differential diagnosis between infantile and mature swallowing with ultrasonography. Visceral swallowing group had a mean age of 10 years 3 months, and somatic swallowing group had a mean age of 17 years 9 months. They reported that genioglossus muscle could serve as a reliable means for differentiating between visceral and infantile swallowing patterns. A year later, Peng et al (109) again carried out an ultrasound investigation and they compared tongue functions between mature and tongue thrust swallowing subjects with mean ages of 21.8 ± 6.1 years and 13.6 ± 6.6 years respectively.

In all the studies performed on tongue function, pressure and dentoskeletal forms, the question whether dentofacial form affects tongue function or vice-versa still remains unsolved even if the adaptive behavior of orofacial musculature is mentioned. Besides, in all the studies on pressure measurements of orofacial musculature cited, the study is based on either adults, or children with normal occlusions. In other studies carried on subjects with open bite, either children or adults are investigated for tongue function or swallowing patterns, or initial effects of tongue cribs are studied by means of different imaging procedures. This brings about the necessity to study the tongue function before and after the correction of an open bite, or the alteration of occlusion after myofunctional therapy. Since the greatest growth changes in the head are being made by facial musculature, it can be assumed that all abnormal pressures should be kept away from the most vulnerable target, the face. As we all know, it is during the transition from deciduous to permanent dentition that most of the damage takes place, and it is during this transition stage that the avoidance of the abnormal pressure habits is of utmost importance. Thus, we planned to base our study on growing open bite subjects as study and control groups, with tongue thrust swallowing pattern. We aimed to investigate the changes in tongue pressure before and after the crib appliance therapy lasting for 10 months and evaluate the adaptive behavior 2 months after the removal of the appliance.

7.2. Discussion of Materials and Method

7.2.1. Discussion of Crib Appliance Therapy

Lack of success of crib therapy as reported by Subtelny and Sakuda (146) was associated with crib wear of less than 6 months. Haryett et al (58, 59), Cozza et al (23), and Giuntini et al (46) suggests keeping the crib in the mouth for more than a year. Our findings suggest that 10-month crib appliance wear is also enough for correction of open bite (Table 2.).

It has been reported that using a compliance-free, fixed appliance for the correction of open bite and inhibition of thumb and finger sucking habits produces more favorable results (25, 46), thus we chose to use a fixed crib appliance in our study.

7.2.2. Discussion of the Measurement Device

There are three principal methods for investigation of the forces and pressures exerted by muscles and soft tissues on various regions of the skeletal system. These are tissue volume measurements, electromyographic measurements, and electrodynamic measurements including strain gauges. Of these methods, strain gauge method was accepted to be more promising and Abrams (1), Jacobs and Brodie (67,69), Winders (166,167), Kydd (88), Proffit et al. (115,116), Gould and Picton (47,48), Lear and Moorrees (90) and Küçükkeleş and Ceylanoğlu (85) are among the investigators who published studies on this subject.

In 1966, Howland and Brodie (63) used resistance bridge transducer as a method for measurement of exerted pressures by buccinator muscle. The general principle involved the conversion of pressure to an electrical potential. This system was accepted as sensitive method for measurement of pressure changes.

In 1989, Kato, Kuroda, and Tagawa (73) developed a telemetric method to monitor the active and passive perioral forces exerted on the maxillary dental arch. The force sensor had a diameter of 6 mm, a thickness of 1 mm and was able to measure forces continuously for 6 hours.

A year later, in 1990, Lindeman and Moore (91) carried out a study on measurements of intraoral muscle force with foil strain gauges, load cells, and pressure transducers bonded to a stent and to a lip bumper. The pressure transducer was found to

be the superior measuring device with respect to size, sensitivity, thermal compensation, factory uniformity, replicability, and validity.

Shellhart et al (130) used a transducer with beam mechanism and a transducer with diaphragm mechanism for evaluation of lip and tongue pressure on tooth position. Both transducer types produced measurements that were reliable and repeatable. The error was smaller for the diaphragm transducer and it was more precise. A year later in 1997, they used EPL6 flatline transducers in order to evaluate changes in lip pressure over a 6-month period when dental arch expansion was simulated (129).

In 1996, Thüer et al (154) described the human cheeks as fluid-filled, double elastic membrane systems. They stated that after a certain amount of the displacement of the cheeks by the movement of an artificial tooth, a plateau was reached with a constant force over a distance of 0.5-1 mm. The conclusion was that the measurements of the resting pressures had to be made within an area of 0-2 mm from the tooth surface. With greater distances, the pressures would increase rapidly. The pressure transducer used in our study has 1 mm thickness. We paid attention for the thickness of the system not being more than 2 mm when the pressure transducer is placed on the teeth by means of carriers.

In 2003, Küçükkeleş and Ceylanoğlu (85) evaluated the changes in lip, cheek and tongue pressures after rapid maxillary expansion using an EPL BO diaphragm pressure transducer connected to a digital strain indicator. The pressure transducer was calibrated using a pressure chamber, which had a pressure manometer. They also reported the pressure transducer to be able to perform reliable and replicable pressure measurements.

Qazi (122) in 2003 also used EPL BO diaphragm pressure transducer in evaluating the buccal and lingual soft tissue pressures in different malocclusions.

In 2005, Ruan et al (124) studied the muscular forces exerted on the deciduous dentition and the relationship between the muscular forces, sex, and oral function. They used a strain gauge computer-aided measuring device with a transducer thickness of only 0.7 mm. The transducer comprised strain gauges and cantilever and was insulated with silicone rubber.

Different kinds of pressure transducers and sensors have been used in different studies. EPL BO diaphragm type pressure transducer is regarded as the most successful

measuring device when the thermal compensation and isolation properties are taken into account (3,90,91,99,100,130,139). Thermal compensation property turns out to be a very important factor, especially in oral functions like swallowing water, where fast adaptation to mouth temperature is needed.

To sum up, as stated in most of the studies in literature, the pressure transducer was found to be the superior measuring device with respect to size, sensitivity, thermal compensation, factory uniformity, replicability, calibration, validity when compared with other devices. Besides, the ability to measure pressure from more than one direction gives the diaphragm-type transducer an advantage for use in intraoral pressure measurement studies. In accordance with this knowledge, we used EPL-BO pressure transducer produced by Entran Company in our study (Entran-Sensors and Electronics, Fairfield, NJ, USA). The producer normally calibrates these transducers. In order to record the pressure measurements in gr/cm^2 , we recalibrated the transducers in a similar way as described in the literature (85,91,130).

7.2.3. Discussion of the Natural Head Posture during Measurements

Downs (28), Bjerin (14), and Moorrees and Kean (101) introduced natural head positioning in orthodontics in 1950's, and numerous researchers have studied its application and established its advantages. Cooke and Wei (22) described the natural head position as the physiologic position of the head while the subject looks into the reflection of his eyes in a mirror located 200 cm ahead.

Archer and Vig (9), Wood (168), Helsing and L'Estrange (60), Thüer and Ingervall (65), Takashashi et al. (149) reported that, head posture should be considered important in evaluating facial morphology and dental equilibrium, since every subject showed pressure changes with the change in head posture.

In the light of the recent studies, it becomes clear that the intraoral pressures are affected with the head posture. Thus, measurements during our study were performed with the subjects in natural head posture in order to eliminate pressure changes that may occur due to head position changes.

7.2.4. Discussion of Measurement Method

While investigating intraoral pressures, different oral functions should be taken into account. Mostly considered oral functions in the previous studies are, rest position, swallowing, chewing, phonation (15, 20, 28, 40, 41, 42, 53, 65, 66, 73, 91, 100, 130, 139, 151, 152, 154).

Light forces acting for enough duration on dentition can move the teeth. Although they apply very light forces in rest position, lip, tongue and cheek muscles can move the teeth as they act on the dentition all the time. During mastication, the teeth move slightly, the alveolar bone and basal bone of maxilla and mandible bend and flex. These changes occur in a matter of seconds, and the teeth and jaws are restored to their original positions as quickly as they were displaced (49,118,139). The duration of force, because of the biologic response, is more important than its magnitude. That is the reason why in almost all the studies especially resting forces are taken into account besides evaluating swallowing, chewing and phonation pressures. Lindeman and Moore (91) stated that chewing and blowing exercises were the least replicable functions besides swallowing and pronunciation in their study in 1990. According to their findings, we measured the tongue pressure during resting, swallowing and phonation. We did not measure tongue pressure during chewing and blowing exercises. The other reason for excluding chewing was that the pressure transducer we used has very thin connection cables and can be distorted.

The carriers, which we prepared for the placement of pressure transducer on the lingual and palatal side of the teeth, were bent from 0.7 mm stainless steel wire. The thickness of the system was measured as 1.7 mm when the pressure transducer was fixed onto the carrier. This thickness does not exceed 2 mm, the upper limit for the precise pressure measurement as stated by Thüer et al (154).

In order to obtain the most accurate pressure values, the highest 5 values appearing on the screen during rest position were recorded. Swallowing and phonation exercises were repeated 5 times in each session and the values on the screen were recorded. For the swallowing function, it is difficult to assess the onset and the end of the function, as there may be a preparatory activity and a complex form of multiple peaks, which appear on the screen. In our study, the maximum value appearing on the screen for each swallow was taken into account. The importance of the repeated

measurements is emphasized in studies performed by Thüer et al (41,65,154) and Peng et al (109).

After initial pressure measurements, we inserted the crib appliance and did not remove during 10-month therapy in order not to disturb the expected adaptive behavior of the tongue. Thus, measurements from upper and lower central incisors were performed only 3 times during the study; at the beginning, at the 10th month; corresponding to the appliance removal and at the 12th month; 2 months after the removal. Measurements from upper molar were performed on the crib appliance during the therapy at the 1st week, 1st month, 3rd month, 6th month, and 10th month.

7.3. Discussion of the Pressure Changes in Study Group and Control Group

7.3.1. Resting Pressures

Most authors agree that measurements during functional exercises provide little information about the influence of the soft tissues on the position of the teeth (42, 94, 118, 153). The normal soft tissue function are of only short duration and, therefore of little importance for tooth position. The position of the tongue at rest is however, important for the position of the teeth (118).

In this study, according to the initial measurements, resting tongue pressure in study group is $16,66 \pm 6,37$ gr/cm² on upper molar, $16,42 \pm 8,95$ gr/cm² on upper central incisor, $15,26 \pm 5,27$ gr/cm² on lower central incisor. The resting tongue pressures in control group are $18,97 \pm 4,92$ gr/cm² for upper molar, $19,5 \pm 14,95$ gr/cm² for upper incisor and $16,6 \pm 3,71$ gr/cm² for lower incisor. The difference between study and control group is statistically insignificant, indicating the homogeneity throughout the selected subjects ($p=0,219$). In the study carried out by Küçükkeleş and Ceylanoğlu initial resting pressure is $16,1 \pm 12,9$ gr/cm² for upper molar and $15,7 \pm 13,6$ gr/cm² for upper incisor. The similarity between the values may be explained by the usage of the same pressure measurement technique although the subjects' ages ranged between 13 and 20 in their study.

In the study carried out by Thüer, Sieber and Ingervall (154), the average maxillary lingual resting pressure value was 1.39 ± 2.03 gr/cm² and the average mandibular lingual resting pressure value was 2.22 ± 3.34 gr/cm². This study is different

from our study from the point of measurement device, technique, and subjects. Their study consists of 24 adults aged 22-29 years with acceptable occlusions while our study consists of growing subjects with anterior open bite and tongue thrusting. Their extraoral measuring system consisted of a bottle of water and compressed air, a pressure transducer and a flow-limiting valve, and an open cannula embedded in a small custom-made acrylic shield (mouthpiece) which is bonded to teeth. The mouthpiece projects 2-3 mm from the tooth surface, the cannula is connected to the extraoral measuring system via 1.3 mm diameter tube passing between the lips at the corner of the mouth. The pressure causes a constant stream of water to escape through the cannula. When the tongue covers cannula, a resistance occurs to the escape of the water. The pressure transducer records the pressure built up in the water system. The diaphragm-type pressure transducer that we used is more sensitive and offers more precise measurements when compared with other technique. Besides, measurement points in their study are at the palatal interdental space between tooth 24 and 25, and at the lingual interdental space between tooth 34 and 35. They inserted the open end of the cannula in the embrasure between those teeth. This placement permits pressure measurements in only one direction. In our study, our measuring points are on the palatal side of upper first molar, upper central incisor and on the lingual side of lower central incisor, near to the dento-gingival junction. The difference between the average resting values may be due to these reasons.

Similarly, in other two studies carried out with the same technique and by the same observers, the resting tongue pressures were lower when compared with ours. They measured tongue pressure from the interdental space between the upper central incisors, lower central incisors and the interdental space between upper left second premolar and first molar. The first study consisted of 25 adults with clinically normal occlusion. The median resting tongue pressure was $-1,7 \text{ gr/cm}^2$ for upper incisor, -0.1 gr/cm^2 for lower incisor and -0.3 gr/cm^2 for upper molar. In the second study they used 20 young adults with clinically normal occlusion and the median lower incisor resting tongue pressure was $-1,2 \text{ gr/cm}^2$ for upper incisor, $0,7 \text{ gr/cm}^2$ for lower incisor and 0.2 gr/cm^2 for upper molar (41,42).

In 1989, Kato et al. (73) developed a telemetric method to monitor the active and passive perioral forces exerted on the maxillary dental arch. The force sensor had a

diameter of 6 mm, a thickness of 1 mm and they kept it in mouth for 6 hours during measurements. The resting pressure on the lingual surface of upper central incisor was 4.0 gm/cm². The reason for lower resting pressure values than our values, may be due to the temperature changes within the mouth as the investigators have reported.

In 1993, Fröhlich et al. (40) evaluated tongue pressure changes after surgical tongue reduction in 21 children and adolescents. Pressure from the tongue was measured from the lingual surface of maxillary central incisors, mandibular central incisors, maxillary and mandibular molars. Resting tongue pressures initially ranged between -13,9 and 20,3 gr/cm² for upper incisors, -8,3 and 70,7 gr/cm² for lower incisors and -2,4 and 32,7 gr/cm² for upper molars. The measuring technique they used was different from ours and the mean age of the study group was 15 years 3 months.

We also have measured negative resting pressures in some of the subjects throughout the study, however, the average resting tongue pressure of the total group turned out to be positive. Some of the previous studies on pressure measurements also report negative resting pressures (42, 65, 152, 154).

The resting tongue pressure on upper molar in the control group of our study was measured as 18,97±4,92 gr/cm², 19,9±6,47 gr/cm² and 19,13±5,81 gr/cm² initially, at the 10th month and 12th month respectively. The resting pressure values were consistent and the differences between the values were statistically insignificant (p>0.05). In the study group, at the time of the crib appliance insertion, resting tongue pressure on upper molar increased up to average 27,17±11,56 gr/cm². The average tongue resting pressures were measured as 21,34±10,95 gr/cm², 20,17±12,93 gr/cm², 17,62±10,75 gr/cm² in the 1st week, 1st month and 3rd month respectively. It continued gradually decreasing in the 6th month with an average value of 12,86±2,84 gr/cm² which was even lower than the initial values. The difference between the values of 6th month and appliance insertion value was statistically significant (p<0.05) whereas it was insignificant when compared with initial values (p>0.05). This finding supports the results found in Küçükkeleş and Ceylanoğlu study (85). They reported that tongue pressures did not reach preexpansion values by the end of the 3rd month and they suggested following the tongue adaptation for a longer period. Later as reported in his thesis (18), the tongue adaptation occurred by the end of 6th month, reaching pretreatment values, which correlates with our findings.

In the 10th month, the average resting pressure on upper molar kept on decreasing to $12,17 \pm 1,45 \text{ gr/cm}^2$. Right after the removal of the crib appliance, resting tongue pressure value was almost the same with an average of $12 \pm 3,65 \text{ gr/cm}^2$. Two months after the removal of the appliance, the average value remained almost the same as the 10th month value. It was measured as $12,57 \pm 3,65 \text{ gr/cm}^2$. The difference between appliance insertion time average resting tongue pressure and 6th month, 10th month, 10th month appliance removal and 12th month are statistically significant ($p < 0.05$). Although the difference between the initial resting pressure and other measurement times are statistically insignificant, the resting pressures in the 6th and 10th months were lower than the initial values. Even 2 months after the removal of the appliance, by the end of 12th month, it did not reach initial values. Similarly, Fröhlich et al. (40) reported that 6 months after tongue surgery resting pressures on molars were lower than they had been presurgically. At the recordings made 12 months after surgery, none of the pressures differed significantly for the presurgical values. Resting pressures were; however, lower than they had been before surgery.

The average resting tongue pressure on the upper central incisor in our control group was measured as $19,5 \pm 14,95 \text{ gr/cm}^2$, $16,93 \pm 3,46 \text{ gr/cm}^2$ and $19,1 \pm 3,79 \text{ gr/cm}^2$ initially, at the 10th month and 12th month respectively. The values were steady and the differences between them were statistically insignificant ($p > 0.05$). The differences between the resting tongue pressure values for lower central incisor in the control group were also statistically insignificant ($p > 0.05$).

The average resting tongue pressure on the upper central incisor in the study group was measured as $16,42 \pm 8,95 \text{ gr/cm}^2$ initially, $13,31 \pm 2,46 \text{ gr/cm}^2$ at the 10th month and $11,63 \pm 4,7 \text{ gr/cm}^2$ at the 12th month. The average resting tongue pressure on the lower central incisor was measured as $15,26 \pm 5,27 \text{ gr/cm}^2$ initially, $11,83 \pm 2,98 \text{ gr/cm}^2$ at the 10th month and $11,91 \pm 4,85 \text{ gr/cm}^2$ at the 12th month. The tongue applied equivalent pressures on upper molar, upper central incisor and lower central incisor. Although the difference between the measurement times were statistically insignificant, there was a decrease in average resting tongue pressure value and it did not reach initial values even 2 months after the removal of the crib appliance.

The average resting tongue pressure on the crib appliance also followed a decreasing path. The values were measured as $21,09 \pm 14,55 \text{ gr/cm}^2$, $18,91 \pm 14,18 \text{ gr/cm}^2$,

22,03±12,52 gr/cm², 17,69±12,49 gr/cm², 13,57±2,67 gr/cm² and 12,8±2,41 gr/cm² initially, at the 1st week, 1st month, 3rd month, 6th month and 10th month respectively. Although insignificant, 10th month resting tongue pressures were lower than initial values. The difference between the 1st month and 10th month resting values were statistically significant ($p < 0.05$).

About tongue functions, Cleall (21) carried out a study on tongue movements using cinefluorography in patients wearing palatal crib. He reported that palatal crib forced the tongue to function in a posterior and higher position. Likewise, Sayın et al. (126) carried out a study on initial effects of the tongue crib on tongue movements during deglutition by means of magnetic resonance imaging. Similar to our study, their study group consisted of 11 patients with a mean age of 11.09±2.02 years and a mean overbite of -5.14±1.83 mm. The control group consisted of 10 subjects with a mean age of 14.5±2.6 years and a mean overbite of 1.6±0.5 mm. Open bite group wore palatal cribs at least 18 hours for 2 weeks to ensure adaptation. They stated that tongue tip was positioned more posteriorly when the crib was in place during deglutition and to compensate for the posterior position of the tongue's tip, adaptive changes occurred in the anterior and mid portions of the tongue's dorsum. In the same way, Cleall (21), Milne (98), and Subtelny (145) stated that the tongue adapts to environmental changes. Fink (37) had suggested that the effectiveness of the crib/spur therapy lies not in restraining action on the tongue dynamically, but instead lies in its ability to redirect the resting position of the tongue into a less critical posture. In our study, we found decreases in resting tongue pressure and even after the removal of the crib appliance, the values did not return to initial values. Although statistically insignificant, our findings suggest the soft tissue adaptation idea, together with the studies mentioned above.

Related with the soft tissue adaptation idea, Soo and Moore (139) investigated intraoral lip pressures in 10 children undergoing lip bumper therapy for 8 months. They reported that resting and speaking lip pressures for the midline transducer showed significant increases 1 month after lip bumper placement and then decreased to near or below pretreatment levels by the end of 7 month, possibly an adaptive response. They concluded that the results suggest an adaptive response of lip muscles. Correspondingly, Moawad et al. (100) examined lip pressure changes after 1 week of simulated dental

arch expansion. Twenty subjects wore a mandibular expansion-simulating stent full-time for 1 week. They measured resting pressure in the midline and right canine areas. Midline lip pressure decreased significantly after 1 week, suggesting an adaptive response.

On the contrary, in the study carried out by Halazonetis et al. (53), the changes in cheek pressures following rapid maxillary expansion were investigated in 15 patients. They reported that soft tissue adaptation was not observed at the end of 3 months retention and the pressures remained approximately the same as the values found after expansion. Their pressure measurement technique was the one described before by Thüer et al (42, 102, 103, 104). We think that the differences in their results may have been due to the differences in their technique.

7.3.2. Swallowing Pressures

Pressures created during swallowing function are extremely higher than pressures created during rest position and phonation. The swallowing pressures we have obtained in our study are in the same line with other studies suggesting the idea (42, 53, 63, 65, 85, 91, 122, 152). Although some workers have found increased tongue pressure during swallowing in anterior open bite patients (87), others have shown that some tongue thrusters exhibit little or no pressure (115).

Fröhlich et al (42) found higher swallowing pressures at the upper molars than at the upper incisors, in 25 adults with normal occlusion. Our findings match their results although our study group consists of open bite subjects. Besides, all of their average values for swallowing pressure on dentition are higher than ours are. These higher values can be attributed to the extraoral pressure transducer incorporated in a water-filled system they have used.

Initial average swallowing pressures in this study for control group were $166,7 \pm 26,47 \text{ gr/cm}^2$ for upper molar, $148,53 \pm 23,09 \text{ gr/cm}^2$ for upper central incisor and $131,97 \pm 22,04 \text{ gr/cm}^2$ for lower incisor. Initial average swallowing pressures in study group were $149,86 \pm 28,28 \text{ gr/cm}^2$ for upper molar, $154,12 \pm 41,12 \text{ gr/cm}^2$ for upper incisor and $138,25 \pm 29,57 \text{ gr/cm}^2$ for lower incisor. The initial values were similar to each other indicating homogeneity between the groups ($p > 0.05$).

The differences between the initial, 10th month and 12th month swallowing pressures in the control group for all the measurement points were statistically insignificant ($p>0.05$). In the study group, after the application of the crib appliance, swallowing pressure on upper molar vastly increased and continued increasing during the 1st week. We think that the increases in both resting and swallowing pressures after the insertion of the crib appliance are due to the restricted area and restricted forward movement of the tongue caused by the crib. After the 1st week, the swallowing pressure showed a gradual decrease and even at session when the crib appliance was removed, the pressure was lower than initial. Two months after the removal of the appliance, the swallowing pressure on upper molar showed a slight increase which is insignificant ($p>0.05$). The differences between the appliance insertion-10th month appliance removal values and 1st week-10th month appliance removal values are statistically significant ($p<0.05$). These results advocate the other authors suggesting that the tongue has an adaptation capability to environmental changes and that adaptation occurs in the anterior and mid portions of tongue's dorsum (21, 98, 126, 145).

Average swallowing tongue pressures on upper incisor were $154,12\pm41,12$ gr/cm², $128,59\pm16,78$ gr/cm² and $136,82\pm17,42$ gr/cm² initially, at the 10th month and the 12th month respectively. Average swallowing tongue pressures on lower incisor were $138,25\pm29,57$ gr/cm², $129,82\pm20,36$ gr/cm² and $138,08\pm16,56$ gr/cm² initially, at the 10th month and 12th month respectively. The differences between values were statistically insignificant ($p>0.05$) but a decrease in pressure values during treatment and a return to initial values 2 months after the removal of the crib appliance should be considered. This may indicate the tongue adaptation to the new position of the incisors created by crib appliance wear.

Besides, the reason for these changes may be in accordance with Fröhlich et al (41) who reported that the lack of correlation between the pressures recorded in the same subjects 2 years later were noteworthy. This may signify that no long-term constancy in the pressures from the tongue on the teeth exists, however, it may also be due to methodological problems. The negative correlations they have found between the size of the overjet, size of the upper dental arch and resting tongue pressure on upper incisors confirm the hypothesis of an adaptive role of the tongue. The tongue adapts to an existing morphological situation rather than actively molding dental arches.

Similarly, Proffit observed smaller pressures from the tongue in Australian aborigines than in Americans, although the dental arches are wider in aborigines (119).

The average swallowing tongue pressure on the crib appliance was $216,43 \pm 65,79$ gr/cm² initially. From the 1st week on, the values showed a regular decrease and were measured as $192,92 \pm 58,33$ gr/cm², $179,09 \pm 57,13$ gr/cm², $171,43 \pm 60,29$ gr/cm², $158,02 \pm 35,83$ gr/cm² and $142,95 \pm 29,2$ gr/cm² at the 1st week, 1st month, 3rd month, 6th month and 10th month respectively. The difference between the initial and 10th month value was statistically significant ($p < 0.05$). The findings on the crib appliance are in agreement with the authors supporting the soft tissue adaptation hypothesis (21, 98, 126, 145). As reported previously that tongue thrust swallowing was a physiologic adaptation to achieve anterior seal in patients with anterior open bite (21, 43, 97, 140, 145, 146, 147, 156), our results also correlate with Proffit (114) who claimed that correcting the tooth positions in open bite cases should cause a change in swallowing patterns.

7.3.3. Phonetic Pressures

Speech is one of the important functions performed during deglutition. However, studies including pressure measurements during speech are very rare. Lindeman and Moore (91) stated that pronunciation of the words 'phone', 'mom', and 'church' had high values of replicability in their study. Thüer et al (151) carried out a study on pressure from the lips and measured pressure during pronunciation of the consonant /p/. They reported that the pressure during pronunciation of the consonant /p/ was highest in the modiolus point (between maxillary canine and first premolar), second highest in the lower midline and lowest in the upper midline. They also reported that mean speech pressures were 4 to 7 times greater than rest pressures. Soo and Moore (139) measured lip pressures during pronunciation of the words 'phone', 'mom', 'pop' and 'wow'. They reported that left side speaking pressures showed no significant changes over time while midline pressures decreased to near or below pretreatment levels, indicating an adaptive response, according to the anatomical location.

Küçükkeleş and Ceylanoğlu (85) measured lip pressure during pronunciation of the vowel /u/, and tongue pressure during pronunciation of the consonant /n/ in their study. During pronunciation, lingual pressure was higher than buccal pressure. They

reported that pronunciation pressures were higher than rest pressures and lower than swallowing pressures as did Kato et al (73). These findings correlate with our findings.

Eslamian et al (36) evaluated tongue to palate contact during speech in subjects with and without tongue thrust using an electropalatovision device. They reported that when pronouncing the consonants, the tongue made contact more anteriorly on the palate than in those without tongue thrust. On the other hand, during the pronunciation of whole words, the contact points were similarly located on the palate, whether the individuals exhibited tongue thrust or not. In the study carried out by Cayley et al (17) in which electropalatographic assessment of tongue function in open bite and non-open bite subjects were investigated, they reported that /d3/ and /df/ phonemes should be included when speech is used to test for the presence of fronted tongue behavior.

Similarly, we aimed to measure the phonetic pressure, during pronunciation of whole words which can be spelt by the touch of the tongue on the palatal side of the upper central incisor area in articulation. We selected the Turkish words ‘pasta’, ‘çiçek’, ‘dede’, and ‘katı’ in accordance with the studies mentioned above including consonants /p/, /ç/, /d/, /t/. The initial pressure values during pronunciation of these words were similar in study and control group, supporting the homogeneity between the groups.

In the control group, there was no significant change in phonetic pressure from the beginning to 10th month and 12th month for neither of the words ($p>0.05$).

In the study group, pressure value for ‘pasta’ showed an insignificant decrease from $31,75\pm12,68$ to $23,79\pm5,74$ gr/cm², from the beginning to the 12th month. The pressure value for the word ‘çiçek’ decreased to $23,88\pm3,61$ gr/cm² from $31,28\pm 6,35$ gr/cm², the pressure value for ‘dede’ decreased to $24\pm6,9$ gr/cm² from $32,37\pm9,14$ gr/cm² and the pressure value for ‘katı’ decreased to $23,28\pm6,15$ gr/cm² from $31,49\pm13,40$ gr/cm² which were significant ($p<0.05$). The changes between pretreatment-10th month and pretreatment-12th month values for ‘çiçek’; similarly pretreatment-10th month and pretreatment-12th month values for ‘dede’ and pretreatment-10th value for ‘katı’ were statistically significant, indicating an adaptation of tongue during and after crib appliance therapy. Although the changes in pressure value for the word ‘pasta’ were insignificant, the average pronunciation values for all the words were lower than initial values, even 2 months after the crib appliance removal.

7.4. Discussion of Lateral Cephalometric Findings in Study and Control Group

The initial values for all parameters in lateral cephalometric x-rays for both study and control group were similar and the differences between the groups were statistically insignificant signifying the homogeneity between the groups ($p>0.05$).

In the study group, the average OB value changed from $-2,12\pm1,12$ mm to $+0,62\pm2,08$ mm ($p<0.05$), whereas in the control group, the initial $-2,83\pm2,07$ mm OB value changed to $-2,33\pm2,75$ mm ($p>0,05$). The difference between the study and control group at the end of 10 month was statistically significant indicating bite closure. Worms (172) reported that spontaneous closure of open bite occurs in approximately 80 percent of 10-12 year old children. Although we did not observe spontaneous closure in control group, and the change in open bite value between the beginning and 10th month was insignificant, open bite followed a trend towards decrease.

The increase in UIT-X value from $70,46\pm5,14$ mm to $73\pm4,79$ mm and the increase in the UIT-PP value from $27,77\pm3,4$ mm to $29,27\pm2,59$ mm were significant revealing upper incisor extrusion ($p<0.05$). The significance of UIT-PP value increase and the change in SN/PP being insignificant indicates bite closure effect of crib appliance in dentoalveolar manner rather than downward movement of palatal plane. This fact is in agreement with Pedrin et al (108) who reported no positive skeletal influence of crib appliance therapy in open bite cases, and contradicts with Cozza et al (23) and Giuntini et al (46) who reported improvement in vertical relationships due to downward rotation of palatal plane. On the other hand, when we compare the changes in UIT-X value in both groups, again the extrusion in study group is significant correlating with Cozza et al (23) study. However, our results suggest the effectiveness of crib appliance as did many authors previously (8, 26, 33, 58, 59, 64, 72, 96, 108, 173).

The upper incisor angle remained unchanged in the study group while in the control group U1/PP and U1/SN angles showed insignificant increases from average $115,33\pm10,61^{\circ}$ to $118,33\pm8,21^{\circ}$ and average $105,25\pm7,03^{\circ}$ to $107,25\pm4,92^{\circ}$ respectively. The maintenance of the upper incisor angle in study group is contradictory to the findings of Pedrin et al (108) and Cozza et al (23) who reported significant retroclination of upper incisors using crib appliance. We should consider that Pedrin et

al used crib appliance for 12 months together with vertical chin cup and their sample size was larger. On the other hand, if we think about the insignificant but continual increase in upper incisor inclination in our control group, we may suppose that the crib appliance prevented the further proclination of upper incisors in our study group and allowed extrusion. The maintenance of the upper central incisor angle may also advocate the belief of some authors that the tongue adapts to the morphological shape rather than shaping the dental arches (21, 43, 44, 97, 114, 119, 140, 145, 146, 147, 156).

Total facial height (N-Me) increase was significant in both study and control group ($p<0.05$). The difference between the both groups for 10th month values was insignificant ($p>0.05$). This was not surprising as they were all growing subjects. Besides the increase in anterior facial height, we found out a significant increase in posterior facial height (S-Go) in the treated group. This resulted in a significant increase in Jarabak value, which indicates a more favorable growth pattern. The difference between the groups was also statistically significant when we compared the 10th month (S-Go) values ($p<0.05$).

In study group, the increases in SNA, SNB and NLA values were small, yet significant ($p<0.05$). ANB value showed slight decrease in study group, while it remained essentially the same in control group, being insignificant for both groups ($p>0.05$). Likewise, SN/MP value showed a slight decrease in study group, while it remained the same in control group, being insignificant for both groups ($p>0.05$).

Interincisal angle (IIA) significantly increased to $120,46\pm 8^\circ$ from $116,62\pm 7,64^\circ$ in study group ($p<0.05$), while there was a decrease in the control group. Lower incisor inclination (IMPA) decreased to $91,27\pm 8,38^\circ$ from $93,08\pm 6,66^\circ$ ($p<0.05$). The distance between the lower incisor tip and mandibular plane (LIT-MP) increased significantly from $40,19\pm 3,39$ mm to $41,23\pm 3,51$ mm, suggesting an extrusion, while the distance between the lower incisor tip and X plane remained essentially the same. This may be due to the significant increase in total facial height and ANS-Me values. Changes in LIT-X and LIT-MP values were insignificant for control group ($p>0.05$).

Distance between the upper molar tip and palatal plane (UMT-PP) significantly increased from $20,85\pm 1,55$ mm to $21,73\pm 1,95$ mm and the distance between upper molar tip and X plane significantly increased from $62,27\pm 4,17$ mm to $64,27\pm 4,17$ mm, indicating upper molar extrusion in treated cases. Similarly, distance between upper

molar tip and Y plane significantly increased from $30,54 \pm 5,87$ mm to $33,19 \pm 5,64$ mm showing molar mesialisation. In control group, although the increases in UMT-PP, UMT-X, and UMT-Y values were insignificant, values for both groups were similar. The significant mesialisation of upper molar in study group may be the result of swallowing and resting pressures of tongue transmitted to the molars through the crib appliance. Our results coincide with the results obtained by Pedrin et al (108). In the same way, distance between the lower molar tip and mandibular plane (LMT-GM) increased significantly from $29,88 \pm 2,69$ mm to $31,27 \pm 2,99$ mm. Although the extrusion of lower molars was insignificant in control group, the results were similar to the treated group. The LMT-GM value being significant but the distance between the lower molar tip and X plane (LMT-X) being insignificant may be due to the increase in total facial height. The distance between the lower molar tip and Y plane (LMT-Y) increased significantly and similarly in both groups, but when we compare the changes in each group, the differences were insignificant. Our results compare well with the findings reported by other authors (23,108) (Table 19.).

7.5. Discussion of Postero-Anterior Cephalometric Findings in Study and Control Group

Initial Postero-Anterior cephalometric values for both study and control group were similar and the differences between the initial values for all parameters were statistically insignificant indicating the homogeneity between the groups ($p > 0.05$).

Upper right molar angulations (URMA) changed from $60 \pm 13,29^\circ$ to $55,5 \pm 13,03^\circ$, and upper left molar angulations (ULMA) changed from $63,46 \pm 11,45^\circ$ to $58,88 \pm 7,85^\circ$ in study group. In the control group, URMA changed from $61,33 \pm 11,09^\circ$ to $60,67 \pm 13,29^\circ$, and ULMA changed from $60 \pm 13,18^\circ$ to $59,5 \pm 10,56^\circ$. Although the decrease in upper molar angulations in study group was more pronounced than the control group, the findings were statistically insignificant for both groups ($p > 0.05$).

Lower right molar angulations (LRMA) changed from $39,89 \pm 8,87^\circ$ to $42,69 \pm 11,5^\circ$, and lower left molar angulations (LLMA) changed from $40 \pm 8,19^\circ$ to $42,81 \pm 9,72^\circ$ in study group. In control group, LRMA changed from $46,42 \pm 11,78^\circ$ to $46,17 \pm 11,36^\circ$ remaining almost the same, and LLMA changed from $43,33 \pm 9,18^\circ$ to $42,67 \pm 8,73^\circ$. The increase in lower molar angulations in study group was higher than

the control group, whereas the changes were statistically insignificant for both groups ($p>0.05$).

The average upper intermolar width (UIMW) changed from $56,42\pm3,16$ mm to $54,04\pm3,63$ mm in treated group ($p<0.05$). In control group, UIMW changed from $54,17\pm2,64$ mm to $52,33\pm3,93$ mm ($p>0.05$). Although the decrease was statistically significant in study group, changes were similar in both groups, thus, at the 10th month the difference between the groups for UIMW value was insignificant ($p>0.05$) (Table 19.).

The average lower intermolar width (LIMW) remained almost the same in study group, as the average value was $50\pm2,88$ mm initially and $50,38\pm3,01$ mm at the end of 10th month. Similarly, in control group, the average LIMW was $50,17\pm3,54$ mm initially and $50,17\pm3,54$ mm at the end of 10th month. The difference between study and control group for LIMW value in the 10th month was statistically insignificant ($p>0.05$).

In our study, the mesial movement of lower molars in both groups and mesial movement of upper molars in study group are statistically significant ($p<0.05$). We assume these mesial movements are due to growth of the subjects, besides, the significant mesial movement of upper molars in study group may be partly due to the forces from the tongue transmitted to the molars through the crib appliance. Decock (27) and Lux et al (95) reported that the mesial movement of molars might be the reason for decrease and combined changes in arch width overtime. In our study, the narrowing of dental arches may be resulting from the mesial movement of molars. We bent the crib appliance passive and easily inserted to the cleats on stone models, and when inserted, we kept the crib appliance in place for 10 months. The possible deformation of the wire due to tongue pressure during deglutition and various uncontrollable intraoral functions of the subjects for 10 months may be the cause for the narrowing of the intermolar width in study group. Another reason for the narrowing of intermolar width may be the cheek pressures which are not confronted by the tongue although crib appliance is in place. We also consider the impingement of crib appliance spurs into the palatal mucosa in most of the subjects during treatment. Although insignificant, the same amount of narrowing in control group supports other investigators' findings, who report gradual reduction in maxillary arch widths in open mouth posture and oral habits (11, 49, 51, 138, 143).

8. CONCLUSIONS

1- Crib appliance therapy resulted in a disturbance in intraoral pressure equilibrium.

2- Open bite showed significant decreases in study group, whereas insignificant changes were observed in control group.

3- Although statistically insignificant, resting tongue pressures on upper first molar remained lower than initial values in study group. The resting tongue pressure values on upper first molar remained the same in control group.

4- Swallowing tongue pressures on upper first molar showed a gradual decrease during 10-month treatment period, and returned to initial values after the appliance removal. Changes in control group were statistically insignificant.

5- Although statistically insignificant, resting and swallowing tongue pressures on upper central incisor remained lower than initial values in study group, whereas they remained the same in control group.

6- Although statistically insignificant, resting tongue pressure on lower central incisor remained lower than initial values and swallowing pressure remained the same. No changes in resting and swallowing tongue pressures were observed in control group for lower central incisor.

7- Significant decreases in tongue pressure during pronunciation of the words ‘çiçek’, ‘dede’ and, ‘katı’ and insignificant changes during the pronunciation of the word ‘pasta’ were observed in study group while changes were insignificant in control group.

8- Resting and swallowing tongue pressures on crib appliance showed significant decreases in study group.

9- IMPA showed significant decrease in study group, while the change was insignificant in control group.

10- Interincisal angle increased significantly in study group, whereas changes were insignificant in control group.

11- Open bite value decreased significantly and upper incisors extruded significantly relative to the palatal plane (PP) and X plane in study group. Lower incisors extruded significantly relative to the mandibular plane (MP).

12- Total facial height increased significantly in both groups.

13- The resting tongue pressures remaining lower than initial values, and significant decreases in resting and swallowing pressures on crib appliance in study group suggest tongue adaptation to the new position created by crib appliance.

Further investigations with larger study groups with longer follow-up measurements may bring out more clear observations.

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10. BIOGRAPHY

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Sağlık Bilimleri Enstitüsü Müdürlüğü'ne;

Marmara Üniversitesi Sağlık Bilimleri Enstitüsü **Ortodonti Anabilim Dalı** çerçevesinde yürütülmüş olan bu çalışma, aşağıdaki jüri tarafından **Doktora tezi** olarak kabul edilmiştir.

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