Longitudinal Effects of Habit-breaking Appliances on Tongue and Dento-alveolar Relations and Speech in Children with Oral Habits

by

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Abstract

A longitudinal pilot study to compare, in children with reduced overbite malocclusions associated with oral habits (finger-sucking and tongue-thrusting), the effects of the experimental Myofunctional Trainer (MFT; Myofunctional Research Co.) and the conventional Bluegrass appliance (BG) on dento-alveolar relations, tongue position, and on speech. **Methods:** The experimental group received the MFT appliance while the control group received the BG appliance. Dento-alveolar changes were assessed by cephalometry and study models. Longitudinal midsagittal 2-dimensional B-mode ultrasound scans of the tongue surface were performed to determine tongue position. Speech acceptability tests were also performed. **Results & Conclusions:** The BG appliance was successful in breaking the finger-sucking habit. The MFT appliance showed only partial success which could be attributed to lack of compliance. At the end of treatment, the open bite was reduced in both groups due to dento-alveolar changes. The BG appliance had a deleterious effect on speech acceptability while in place, while there was no such effect with the MFT appliance.

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(In the name of Allah, Most Gracious, Most Merciful)

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List of Abbreviations

BG	Bluegrass appliance
CHASE	Comfortable Head Anchor for Sonographic Examinations
MFT	Myofunctional trainer appliance
SD	Standard deviation
Ultra-CATS	Ultrasonographic Contour Analyzer for Tongue Surfaces software program
VCV	Vowel-consonant-vowel sequence

Cephalometric Landmarks and Measurements Abbreviations

A	A Point, deepest point in the concavity of the anterior maxilla between the anterior nasal spine and the alveolar crest
ANB	Angle formed between A, N and B points
ANS	Anterior Nasal Spine
B	B Point, deepest point in the concavity of the anterior mandible between the alveolar crest and pogonion
Cd	Condylion
Gn	Gnathion
LFH	Lower face height
Lower Lip to E	Lower lip to Esthetic line
Lower 1 to MP	Angle formed by mandibular incisor and mandibular plane
Max Unit Length	Maxillary unit length
MdLength	Mandibular length
Me	Menton
S	Sella
SNA	Angle formed by sella-nasion and A point
SNB	Angle formed by sella-nasion and B point
ULip to E Line	Upper lip to Esthetic line
Upper 1 to SN	Angle formed by maxillary incisor and sella nasion line

1. Introduction

Much attention has been directed toward oral habits, such as non-nutritive sucking habits and tongue-thrust, as possible causes of unbalanced functional forces on the developing dentition. Unbalanced functional forces are potential aetiologic factors in the development of dento-skeletal abnormalities and hence possible aetiologic factors in malocclusion. This is based on the theory of craniofacial growth proposed by Moss in the 1960s in his "functional matrix theory" (Moss, 1962), which holds that growth of the face occurs in response to the functional needs and effects of the soft tissues surrounding the bony structures of the maxilla and the mandible. The activity of the masticatory muscles, the tongue and the muscles of the cheeks and lips play a major role in the developing occlusion and relapse of orthodontic treatment (Graber, 1963; Moyers, 1988). It is essential when studying the dental malocclusion related to oral habits to assess the abnormal function of different soft tissues including the tongue.

The tongue consists of multiple muscles that are coordinated to produce very complex movements. Because of this complexity and the nature of the tongue as a soft tissue, it is difficult to study it objectively using regular orthodontic techniques. However, in the treatment of malocclusion it would be necessary to obtain more information about soft tissue changes, especially the tongue. These changes are an important factor in the relapse of orthodontic treatment. It is also important to study the effects of intraoral appliances on speech, especially in children because speech is considered a basic milestone in the development of a child. The aim of this pilot study was to compare, in children with reduced overbite malocclusions associated with oral habits (finger-sucking and tongue-thrusting), the effects of the experimental MFT and the conventional BG on dento-alveolar relations, on tongue position at rest and during physiologic movement, and on speech.

2. Literature Review

2.1. Habit Definition

A habit is defined as a repeated pattern of behaviour which is usually a normal phase of development but persists beyond that period or is initiated inappropriately at a subsequent time. The person who engages in the habit often does not recognize this habitual behaviour. The Merriam-Webster online dictionary defines a habit as a way of acting, fixed through repetition, which implies conducting actions unconsciously.

2.2. Oral Habits

Oral habits are common in children. These habits include: non-nutritive sucking habits (thumb, finger and pacifier sucking habits), tongue-thrusting, tongue sucking and lip or nail biting habits. The majority of oral habits are called non-nutritive sucking habits. Early in life most children engage in thumb-sucking or other non-nutritive sucking habits. Digital sucking is considered natural in infancy and almost 100% of children engage in this habit within the first year (Kravitz & Boehm, 1971). Near the end of early childhood and the beginning of grade school, any prolonged oral habit is considered socially unacceptable and can lead to undesirable dental effects.

From a psychological point of view, habits are part of the normal sequence of maturation in children. On the other hand, habits are considered a problem with a possible need for intervention. Intervention may be needed if: it extends for a long period, causes physical damage, or if it is extensive in a way that it interferes with the child’s physical, social, or cognitive development (Shroeder, Gordon, & Hawk, 1983).

2.2.1. Thumb or Finger-sucking Habit

Thumb or finger-sucking habits usually begin early in life, often noted on prenatal ultrasound examinations (Sparling, Van Tol, & Chescheir, 1999). Usually a childhood habit is carried over from this early natural developmental phenomenon, but it can also start later in childhood (Cerny, 1981). With time, this habit diminishes and most children quit the habit under social pressure from their older siblings or peers (Gellin, 1978; Schneider & Peterson, 1982). According to Traisman and Traisman (1958) most children quit the habit by 3.5 to 4 years of age with few or no long-term consequences. Rarely will this habit continue into adult life where one would face a myriad of consequences (Smith, 1996).

2.2.1.1. Thumb or Finger-sucking Aetiology

There are several theories regarding the reasons for the prolongation of the thumb-sucking habit: 1) Levy (1937) stated that the finger-sucking habit is caused by insufficient feeding and inadequate satisfaction of the sucking needs during infancy. 2) Other researchers theorize that the child's emotional disturbance is a factor. Proponents of this theory believe that forced cessation of the habit will force the individual to perform another negative behaviour (Massler & Wood, 1949). However this theory is not supported and children with prolonged digit sucking habit have not been found to have higher stress than other children (Vanderas, Voila, & Papagiannoulis, 2001). 3) Anke (1971) proposed that the aetiology of prolonged thumb-sucking behaviour was related to a learned behaviour that produced pleasure for the child, and hence any device that prevents the child from achieving that pleasure will successfully break the habit. To examine his theory, Anke inserted a 0.5 mm thick removable splint over the maxillary teeth of his study group. The thumb-sucking habit in this group was significantly reduced in comparison to a control group. He claimed that this was the first study to prove that pleasure is an aetiological factor for a prolonged thumb-sucking habit. Different researchers have successfully used habit-breaking appliances to break unfavourable oral habits without any overt negative behavioural consequences (Greenleaf & Mink, 2003; Haryett, Hansen, & Davidson, 1970; Haskell & Mink, 1991).

It appears that the habit is a learned behaviour and the child achieves pleasure by doing it. Any means to stop the pleasure will successfully break the habit. There is no literature to support that the use of a habit-breaking appliance will cause negative behaviour or emotional disturbance to an individual. The theory stating that thumb-sucking is caused by inadequate satisfaction of sucking during infancy remains unsupported.

2.2.1.2. Thumb or Finger-sucking Prevalence

Different prevalence statistics of thumb-sucking habits have been reported in the literature. The prevalence is higher in developed countries than in developing countries (Svedmyr, 1979). Larsson (1994) indicated that digit sucking habits in Swedish children have decreased significantly over the years from approximately 30-50% in the 1970s to about half of that in the 1990s. He explained the reason for this decline was the introduction of pacifiers. Larsson, Ogaard and Lindsten (1992) reported that 10-19% of 3-year-old children were finger suckers in Sweden and Norway. Curzon (1974) explained that he did not notice any evidence of thumb-sucking when he examined and treated over 1,000 Inuit children in the Canadian Arctic. In an examination of 255 Jordanian children, 1-6 years of age, 14% were thumb-sucking (Janson & Fakhouri, 1993). Farsi and Salama (1997) assessed the prevalence of thumb-sucking in Saudi children and reported a prevalence of 10.46% in a sample of 583 children between the ages of 3 to 5 years. Kharbanda, Sidhu, Sundaram and Shukla (2003) found in a study of 5,554 Delhi children aged 5-13 years that 0.7% of these children had a thumb-sucking habit; they also found that girls had a greater prevalence of the thumb-sucking habit than boys. In a study of 2,018 Japanese children, between the ages of 3 and 5 years, about 20% were engaged in finger or thumb-sucking habits (Fukuta, Braham, Yokoi, & Kurosu, 1996). While most children quit the finger-sucking habit at school age, some would continue the habit. Egermark-Eriksson (1982) used a cross-sectional survey of 402 children to find that 20% were finger suckers at the age of 7 years, while only 3% engaged in the habit at 11 years and none at 15 years of age still performed this habit. The author used a questionnaire filled out by parents to confirm habit presence or absence.

Finger-sucking has been reported to be more prevalent in girls than in boys (Egermark-Eriksson, 1982; Larsson et al., 1992). However in a recent longitudinal study, Bishara, Warren, Broffitt and Levy (2006) found no difference between boys and girls (1 and 8 years of age) in their digit-sucking habits. This is consistent with the reports from Bosnjak, Vuievi-Boras, Mileti, Bozi and Vukelja (2002) and Farsi and Salama (1997).

The incidence of finger-sucking habits is less in children at the stage of the mixed dentition (Bishara et al., 2006). Larsson (1971) estimated the prevalence of thumb-sucking in the Swedish population to be 30% in young children and this decreased to 12% by 9 years of age.

In summary, different reports for the prevalence of the finger-sucking habit have been shown in the literature. This is due to the fact that these habits are surveyed at different ages and because of the use of different methodologies, either longitudinal or cross-sectional studies. Most of these studies used a parental questionnaire to confirm habit existence and the duration of the child's habit. Overall, there is a decrease in the prevalence of the finger-sucking habit with age. New reports indicate that there is no difference in prevalence between boys and girls.

2.2.1.3. Effects of Finger-sucking Habit

Different effects of prolonged sucking habits have been reported in the literature, which include callus formation, irritation eczema and herpetic whitlow of the fingers, digital deformations and increased chance of poison ingestion (Rankin, Jabaley, Blair, & Fraser, 1988; Reid & Price, 1984; Srinivasan, Hutchinson, & Burke, 2001). In addition, there is an increase in other accessory habits such as hair pulling (Friman & Hove, 1987). Prolonged finger-sucking habits are considered to be socially unacceptable by peers and family. This might prevent the child from socializing with others (Al-Jobair & Al-Emran, 2004; Friman, McPherson, Warzak, & Evans, 1993). Many parents are aware of the habit and they will often try to seek counselling and treatment to break the habit (Al-Jobair & Al-Emran, 2004). There is an agreement among dental professionals that prolonged finger-sucking habits are possible aetiologic factors in the development of malocclusion (Proffit, 2000).

2.2.1.4. Effects of Finger-sucking on Occlusion

The prevalence of anterior open bite, maxillary protrusion and distal step molar occlusion are higher in children with finger-sucking habits (Fukuta et al., 1996). The prevalence of open bite malocclusions have shown to increase with continuation of these habits (Warren et al., 2005). Fukuta et al. (1996) stated that the effects of finger-sucking habits appear to be on the anterior region of the dentition before the age of three. He made a recommendation to stop the habit by 3 to 4 years of age. Modeer, Odenrick and Lindner (1982) on the other hand, suggested that the finger-sucking habits should be stopped at a younger age, around 2 years, due to the increase in the incidence of unilateral crossbite malocclusions. In a study by Linder and Modeer (1989), the relationship between finger-sucking habits and posterior crossbites in preschool children was examined. The authors suggested that finger-sucking was an aetiological factor in the development of unilateral crossbite malocclusion. However, more effects were found with dummy sucking than with finger-sucking. They stated that another effect of the finger-sucking habit was a reduced overbite in the primary dentition. More effects were found with an increase in intensity (hours/day) and duration of the habit (Lindner & Modeer, 1989). Vazquez-Nava et al. (2006) performed a longitudinal study on 1,160 children aged 4 to 5 years old. These children were followed from 4 months of age. Findings revealed that a non-nutritive sucking habit was an important risk factor in posterior crossbite malocclusion. These habits were also significant risk factors in anterior open bite in children younger than 5 years of age. The authors also included allergic rhinitis as a risk factor, alone or together with non-nutritive sucking habits, in the development of an anterior open bite. Bowden (1966) studied the effects of a prolonged sucking habit on the mixed dentition. He found that the prolonged habit was associated with open bite tendency, skeletal class II dental base relationship, tongue-thrust activities and tongue to lip rest positions. Bowden's sample was taken from the University of Melbourne Child Growth Study where a total of 116 children were followed from the age of 2 to the age of 8 years. However, Bowden did not find an association between the sucking habit and posterior crossbite malocclusion.

In summary, a prolonged finger-sucking habit is a risk factor in malocclusion. The predominant effect of thumb-sucking is anterior open bite malocclusion. A posterior crossbite might be associated with the finger-sucking habit, but it occurs more with prolonged pacifier use. It was found that the longer the habit, the more the associated damage to the primary and permanent dentition (Warren et al., 2005).

2.2.1.5. Pathophysiology of Finger-sucking Damage to Occlusion

Several studies have been conducted to understand the pathophysiology of finger-sucking damage to the occlusion. Ahlgren (1995) conducted a study using Electromyography (EMG) to examine the activity of the mentalis, buccinator and lip muscles during non-nutritive sucking habits. Contrary to previous thought, he found more electromyographic activity in the lip and mentalis muscles than in the buccinator muscle when he examined thumb-sucking children. He stated that this finding explained the V-shaped dental arch in thumb-sucking individuals. The author hypothesized that the combined negative pressure and lower tongue position during thumb-sucking were factors that lead to the formation of this arch form. Luffingham (1970) examined the intra-oral pressure that developed during finger-sucking. He found that during the finger-sucking habit not all individuals developed negative intra-oral pressure. Also, in the cases where negative pressure was produced, it was not always associated with increased pressure from the cheek. The author concluded that the crossbite that is seen in some finger-sucking children might not be related to the negative pressure that is produced by the sucking action nor caused by pressure from the cheeks. That was in agreement with Ahlgren's finding. One shortcoming of the Luffingham's study is the relatively small sample size of 9 subjects. Proffit (2000) has stated that the anterior open bite malocclusion seen in thumb-sucking individuals is caused by interference to eruption of the incisors accompanied by eruption of the posterior teeth. He indicated that the possible cause for the posterior crossbite malocclusion is a combination of lower tongue position and increased cheek activity during sucking. Larsson and Ronnerman (1981), contrary to what Proffit hypothesized, found that the clinical crown length in 9-13 year old children with prolonged finger-sucking habit was longer than that of children without this habit. They explained this finding by showing that the open bite was not caused by arrested eruption of the incisors, but was probably caused by modelling of the alveolar process. The authors indicated that inhibition of the vertical growth of the anterior maxillary process might self-correct after stopping the habit. However, if the child continued the finger-sucking habit after pubertal growth, permanent effects on occlusion are anticipated and self-correction might not occur. Possible factors leading to retention of this abnormal malocclusion include abnormal tongue and lip functions (Bowden, 1966; Turner, Nattrass, & Sandy, 1997).

2.2.1.6. Treatment Strategies for Thumb-sucking Habit

The American Academy of Pediatric Dentistry produced a statement regarding prolonged non-nutritive sucking habits. For children over 3 years of age with prolonged non-nutritive sucking habits, the Academy recommends a professional evaluation with the possibility of intervention to break these habits (American Academy of Pediatric Dentistry Council on Clinical Affairs, 2005). Current literature is emerging on timing of habit-breaking. Past literature suggests that habit-breaking with the use of appliances should not start until eruption of the permanent teeth. This recommendation was due in part to the previous opinions that little if any damage is expected in the permanent dentition (Gellin, 1978; Proffit, 2000). In response to these opinions, several organizations including the American Academy of Pediatrics, American Academy of Pediatric Dentistry, American Association of Orthodontics and the American Dental Association have adopted a statement on sucking habits. The statement explains that until permanent teeth erupt in the mouth, habits do not create permanent damage and that any damage is usually reversible once the habit stops. The recent literature shows that sucking habits have detrimental effects on occlusion, and these effects extend well beyond habit elimination (Warren et al., 2005). The recommendation is now to stop the habit by the age of 3 years (American Academy of Pediatric Dentistry Council on Clinical Affairs, 2005).

Methods for habit intervention include counselling, positive reinforcement, a calendar with rewards, an adhesive bandage, bitter nail polish, long sleeves and appliance therapy. Before trying to break the habit many authors explained that both parents and children should express their willingness to stop the habit (Cipes, Miraglia, & Gaulin-Kremer, 1986; Proffit, 2000). The treatment usually starts by talking to the child while explaining the potential damage that might occur to their dentition if they continue the habit. Positive reinforcement is also used to encourage parents to reward their child for each day he or she does not perform the habit. A calendar is used to record the child's progress (Cipes et al., 1986). Wearing gloves during sleep has also been used (Ellingson et al., 2000; Lassen & Fluet, 1978). It is important to note the accessory movement of the other hand that is accompanied by finger-sucking and its importance in habit-breaking e.g., some children like to hold a teddy bear or blanket while performing the habit. In order to stop the sucking-habits these objects should be removed from the child's hand (Friman, 1988; Watson, Meeks, Dufrene, & Lindsay, 2002). All of the previous methods that are used to stop the finger-sucking habit have been reported in the literature with variable success rates (Cipes et al., 1986; Ellingson et al., 2000; Friman, Barone, & Christophersen, 1986). It is recommended to start with the least invasive methods (e.g., counselling, positive reinforcement, the calendar) before using habit breaking appliances (Schneider & Peterson, 1982; Proffit, 2000).

Some children need additional help to stop the habit and in that case habit-breaking appliances are indicated. Habit-breaking appliances are either fixed or removable. Graber (1958) reported 92% success with fixed appliance therapy. One of the fixed appliances used to break the habit is the palatal crib appliance (Cozza, Baccetti, Franchi, & McNamara, 2006; Haryett, Hansen, & Davidson, 1970). This appliance is effective in habit-breaking; however, the negative emotional reactions and effects on speech and eating are evident (Haryett et al., 1970). There are many disadvantages to the use of the palatal crib appliance in habit-breaking e.g., tongue irritation, difficulty to maintain good oral hygiene and self-inflected trauma (Proffit, 2000).

The success of habit-breaking appliances is usually assessed by asking the parents and the child about the history of habit-breaking with positive reinforcement to the child for stopping the habit. This is done at each follow-up appointment (Cipes et al., 1986; Gellin, 1978). One appliance that is of special interest to paediatric dentists is the Bluegrass (BG) appliance.

2.2.1.7. Bluegrass (BG) Appliance

Haskell and Mink (1991) described a non-punitive fixed appliance to stop thumb-sucking which they called the Bluegrass (BG) Appliance. They recommended the BG appliance in mixed or permanent dentition stage when the child had expressed his/her desire to stop the habit. The appliance consists of a Teflon roller that is placed on the anterior maxilla and is attached to a wire that extends to the molar teeth. The only purpose of the appliance is to aid the child in habit cessation. The BG appliance serves as a reminder and it also acts as a physical barrier that eliminates the pleasure of the sucking habit. While the habit is typically stopped within the first month of insertion, the appliance should be left inside the mouth for at least 4 to 6 months to ensure that the habit is completely eliminated. After appliance insertion, parents are advised to follow up with the treating dentist for 2 weeks and every 4 to 8 weeks thereafter. Confirmation of habit-breaking is obtained from parent history (Greenleaf & Mink, 2003; Haskell & Mink, 1991).

The BG appliance has been shown to be a successful appliance for thumb or finger-sucking habit-breaking (Haskell & Mink, 1991). Greenleaf and Mink (2003), in a retrospective study, showed a 93% success rate of the BG appliance in breaking the finger-sucking habit. The history of habit breaking was confirmed by the patient and/or parents and was recorded in the patient's chart. In that study, the treatment was marked as successful when the child had stopped the habit and was not engaging in it at each follow-up appointment until the end of treatment. However, the authors did not state if a long-term follow-up was performed after appliance removal. It is important to know whether a long-term habit-breaking is achieved. The utility of the BG appliance in treating the tongue-thrust habit has not been tested.

In their retrospective study, Greenleaf and Mink (Greenleaf & Mink, 2003) included 30 out of 41 patients presenting for treatment of a thumb-sucking habit at the University of Kentucky Paediatric Dental Clinic over a period of 7 years. Of the excluded 11 subjects, 6 were still in active treatment, while 5 did not present for follow-up. The total time for habit cessation was 12.3 weeks ± 12.2 weeks. Greenleaf and Mink (Greenleaf & Mink, 2003) suggested that the use of the BG can serve as "a neuromuscular stimulant for the tongue" which they claimed might be used for speech therapy.

2.2.1.8. The Pre-orthodontic Myofunctional Trainer Appliance

Recently, a new functional appliance, the Myofunctional Trainer (MFT; Myofunctional Research Co., Australia), has been developed. Its developers claim that this appliance can break unfavourable oral habits (tongue-thrust, non-nutritive sucking habits), produce favourable dento-alveolar changes and re-position the tongue into a favourable position. One study has shown that this appliance produces favourable dento-alveolar changes that lead to reduction of overjet in children with Class II, division 1 malocclusion (Usumez et al., 2004). This study included 20 patients in a control group that received no treatment, whereas 20 patients received the pre-orthodontic trainer appliance. The authors reported the cephalometric changes at the end of treatment and compared these to the control group. They did not indicate if the investigators were blinded to both groups.

No study has been conducted to indicate whether the MFT appliance can break oral habits in addition to the inducing favourable myofunctional actions on different oral muscles, primarily the tongue. It is of clinical relevance to determine whether this appliance can help in re-positioning of the tongue to assume a favourable position.

2.2.2. Tongue-thrust Habit

Many names for the tongue-thrust habit have been reported in the literature. Tongue-thrust is also called tongue-thrust swallow, visceral swallow, infantile swallow, reverse swallow, deviant swallow, perverted swallow, tongue-thrust syndrome and atypical swallow. Some researchers have indicated that the tongue-thrust is a persistent infantile swallow caused by delayed maturation (Tulley, 1969). However, there is no proof to support this as yet.

2.2.2.1. Tongue-thrust Definition

There are different definitions for the tongue-thrust that have been reported in the literature that lead to different reports for the prevalence of this habit. Much of the literature about the tongue-thrust is from the 1970s. Since that time controversy exists among researchers in dentistry and speech-language pathology, whether it is an adaptive behaviour or an aetiological factor in malocclusion. Tulley (1969) defined the tongue-thrust as a forward movement of the anterior tongue between the teeth to contact the lower lip during swallowing and in speech. However, he did not include the abnormal forward tongue rest position in his definition, whereas Proffit and Mason (1975) defined the tongue-thrust as the protrusion of the tongue against or in between the anterior dentition with excessive circumoral muscle activity during swallowing. They stated that one or more of the following conditions should exist to define the thrust: first, the tongue should move forward to contact the lower lip during swallowing. Secondly, the forward movement of the tongue between the anterior teeth during speech may be observed. Finally, a forward positioning of the tongue with the tip of the tongue positioned between or against the anterior teeth at rest. Brauer and Holt (1965) defined tongue-thrust by any movement in the lips of an individual during swallowing. The authors confirmed this by observing the position of the tongue during swallowing. If the tongue was thrusting in between the teeth and the teeth were not in centric occlusion then they marked this as a tongue-thrust. To diagnose the tongue-thrust swallow, the lips were opened during swallowing to visually observe the forward tongue movement between the teeth (Cooper, 1973). An Ad Hoc Committee from the American Speech-Language-Hearing has produced a statement regarding the tongue-thrust habit. They describe this behaviour as a labial-lingual posturing function (Mason et al., 1989). In the description of atypical oral-facial patterns, the statement describes the forward resting tongue position along with tongue protrusion during swallowing as tongue-thrust. However, the Committee did not address the issue of how to diagnose the tongue-thrust during swallowing except by stating that it is tongue protrusion during swallowing.

2.2.2.2. Normal Tongue Position during Swallowing

The movement of the tongue during swallowing in adults, who do not have dental malocclusion, can be described as follows: the tongue tip will retract when the bolus enters the mouth, then the tongue tip will be pushed against the incisive papilla and the central incisor area. This will form the pressure needed to push the bolus back inside the mouth (piston action), and at that time the dorsal part of the tongue will be depressed. Consequently, the soft palate will be elevated and the dorsal part of the tongue will approximate the palate and the bolus will be pushed to the pharynx (Kawamura, Nojima, Nishii, & Yamaguchi, 2003). However, deglutition differs among subjects with different ages and maturation levels (Dubner, Sessle & Storey, 1978). One example is the infantile swallow; that is characterized by tooth-apart swallow where the tongue usually thrusts between the gum pads to contact the lower lip in order to achieve an anterior oral seal. The teeth-apart swallow can also be seen in adults swallowing saliva or water and so would not be considered as an abnormal swallow (Dubner et al., 1978). In the latter case, the activity of the muscles of facial expression would be considered as reflecting normal activity. However, in case of hard food, the mandible needs to be stabilized and tooth contact is necessary to be achieved through the muscles of mastication. In this case, any activity of the muscles of facial expression would be abnormal (Dubner et al., 1978).

On the other hand, in subjects with anterior open bite, the tongue tip protrudes between the maxillary and mandibular anterior teeth to achieve an oral seal. Consequently, the dorsum of the tongue will be positioned in a forward and inferior position during swallowing compared to subjects without an anterior open bite (Kawamura et al., 2003).

2.2.2.3. Tongue-thrust Classifications

Upon review of the literature, we found no recent classifications for the tongue-thrust. Most of the previous classifications were expert opinions. Tulley (1969) used a cinephotography technique to study and classify tongue-thrust movements. He proposed the following classification:

1. **Tongue-thrust as a habit:** In this case the habit will be eliminated when the malocclusion is corrected. There is no need for any tongue re-positioning therapy e.g., thrust associated with thumb-sucking habit.

2. **Endogenous (innate) tongue-thrust:** This is a familial condition and seen in siblings and in one of the parents. Sometimes there is no malocclusion and hence there is no indication for treatment. But if there is malocclusion therapy is usually not effective.
3. **Adaptive tongue-thrust:** There is no oral seal and the tongue protrudes and rests more forward in position. The tongue will contact the lower lip from over the lower incisors to achieve the oral seal. Once the malocclusion is corrected the thrust will be eliminated.
4. **Macroglossia:** Pathologic or grossly abnormal tongue. However, true macroglossia is very rare.

Another classification for the tongue-thrust has been proposed by Brauer and Holt (1965). This classification depends on the effect of the tongue-thrust habit rather than the aetiological factors. They suggested the following classification:

- Type I: Non-deforming Tongue-thrust
- Type II: Deforming Anterior Thrust
- Type III: Deforming Lateral Tongue-thrust
- Type IV: Deforming Anterior and Lateral Tongue-thrust

Proffit (2000) stated that the current opinion on tongue-thrust is that it is seen in two conditions: First, tongue-thrust as a normal developmental stage of maturation. Children in young ages will have this condition as a transitional stage, which will disappear with maturation. Second, is the adaptive tongue-thrust where the tongue is thrust in between the displaced teeth but it is not causing the teeth displacement.

2.2.2.4. Prevalence of Tongue-thrust

Almost all infants exhibit tongue-thrust activity during deglutition. This patterns changes with age and maturation of different orofacial structures. Fletcher, Casteel and Bradley (1961) studied tongue-thrust in different ages and found that the prevalence of tongue-thrust in children 6, 7, 8, 9 and 10 years was 52.3%, 52.8%, 38.5%, 41.9% and 34%, respectively. Hanson, Barnard and Case (1969) found that in 214 preschool children, 39% had a tongue-thrust for saliva swallowing, 55% for liquid swallowing and 68% for solid swallowing. During adolescence tongue-thrusting becomes less frequent (Fletcher et al., 1961).

In summary, there are no consistent reports for the prevalence of the tongue-thrust swallow. The prevalence varies according to the definition of tongue-thrust and the age group. What is evident is that the tongue-thrust decreases with age (Fletcher et al., 1961). In some younger age groups tongue-thrust is normal rather than abnormal. Growth and maturation might be an explanation for the reduction of tongue-thrust with age.

2.2.2.5. Effects of Tongue-thrust on Occlusion and Speech

The effects of tongue-thrust on occlusion have been the subject of controversy in much of the literature. Tongue-thrust activity may be a contributing or a maintaining factor in malocclusion, lisping or both.

Tongue-thrusting habit is associated with anterior open bite malocclusions (Huang, Justus, Kennedy, & Kokich, 1990; Moyers, 1988; Straub, 1960), protrusion of incisors (Rock, 1988; Straub, 1960), spaced mandibular and maxillary anterior dentition (Lebrun, 1985), increase in tendency of distal occlusion and increased overjet (Melsen, Stensgaard, & Pedersen, 1979). Subtelny and Subtelny (1973) stated that although it was linked to malocclusion, abnormal swallow was not always associated with dental malocclusion. As well, protrusion of the tongue in between the teeth may not always be abnormal.

Tongue-thrusting has been associated with speech problems, such as anterior lisp (Graber, 2000) and articulatory problems with some consonants (S, Z, T, D, L, and N) (Kellum, Gross, Hale, Eiland, & Williams, 1994; Teanech & Fogel, 1974). The presence of open bite malocclusion may result in articulation errors, although this depends on the severity of malocclusion and the child's compensative ability (Luke & Howard, 1983). Tulley (1969) examined over 1,500 11-year-old school children for a tongue-thrust habit. He found that even though some children had an excellent occlusion they displayed lisping in their speech. Proffit and Mason (1975) explained that there was no definite causal relationship between lisping and tongue-thrusting although they might occur simultaneously. Although it has been reported that correction of open bite malocclusion can eliminate a lisp, this is not seen in all cases (Luke & Howard, 1983).

2.2.2.6. Relationship between Tongue-thrust and Thumb-Sucking

All open bites are accompanied by a tongue-thrust (da Silva Filho, Gomes Goncalves, & Maia, 1991; Nahoum, 1975). In cases of the thumb-sucking habit, once the habit has been eliminated spontaneous correction of the open bite usually occurs except in cases where there are other associated habits. Other habits could include tongue-thrusting, mouth breathing and hyperactive perioral muscles. In a study of 723 children aged 10-11 years in Denmark, there was an increase in the tendency of tongue-thrust swallow and teeth apart swallow in children with a thumb-sucking habit compared to a control group (Melsen et al., 1979). da Silva Filho et al. (1991) described the differences between the anterior open bite in tongue-thrust in comparison to open bite caused by thumb-sucking. In thumb-sucking the anterior open bite was circular in contour. In comparison, the contour of the open bite was more diffuse or rectangular in shape in subjects with a tongue-thrust swallow.

2.2.2.7. Tongue-thrust, Unbalanced Forces and Malocclusion

For many years there have been theories regarding the tongue as a balancing force that counteracts the opposite forces of the cheek and lips in the development of normal occlusion. Some theories have related the tongue position, tongue strength, and tongue size to development of malocclusion (Brodle, 1953). Straub (1960) argued that the tongue-thrust and abnormal swallow will produce an open bite malocclusion, and if not corrected this will lead to relapse after finishing orthodontic treatment. He advised that a speech pathologist or therapist be involved in the majority of cases of open bite malocclusion. The purpose would be to re-educate the perioral muscles and assist the tongue in assuming a normal position.

A number of researchers were not able to demonstrate a cause and an effect relationship. While it was possible to train the perioral muscles of tongue-thrusting subjects and to strengthen their tone to counteract the tongue-thrust, there were no dento-alveolar corrections as a result of this muscle exercise (Barber & Bonus, 1975). In children with open bite malocclusion there was inconsistent lingual pressure during the tongue-thrust swallow. This does not support a cause and an effect relationship in the development of the anterior open bite (Proffit, Chastain, & Norton, 1969). Proffit and White (1991) argued that the tongue-thrust swallow in patients with anterior open bite was an adaptive process to achieve an oral seal. However, Proffit (2000) has explained that the position of the tongue at rest is a possible aetiologic factor in the anterior open bite malocclusion. The tongue rest posture causes a small force delivery over a long period of time, which will be similar to orthodontic forces that will lead to orthodontic tooth movement. In contrast, during the tongue-thrust swallow the forces that are produced are intermittent and acting for a short period of time. These types of forces do not produce significant tooth movement (Proffit, 1978; Wallen, 1974).

2.2.2.8. Treatment of Tongue-thrust

Different methods have been attempted to correct the tongue-thrust habit with variable success. The American Academy of Pediatric Dentistry states that the management of the tongue-thrust may include “myofunctional therapy, simple habit control, habit-breaking appliances, orthodontics and possible surgery” (American Academy of Pediatric Dentistry Council on Clinical Affairs, 2005). In a longitudinal study of tongue-thrust patients undergoing orthodontic treatment, Andrianopoulos and Hanson (1987) found that there was less stability of overjet correction in patients who received orthodontic treatment without myofunctional therapy for their tongue-thrust compared to patients who received the therapy. There is a strong relation between the position of the mandible, occlusal contact and tongue activity in tongue-thrusting subjects (Dahan & Lelong, 2003). The enhancement of patient awareness of occlusion might aid in controlling tongue-thrust during different activities (Dahan & Lelong, 2003). However, Subtelny (1970) studied the orofacial structures with cephalometry and cineradiography in patients receiving myofunctional therapy alone without orthodontic treatment. He noticed that there were minimal changes in structure as a response to the myofunctional therapy. Proffit and Ackerman (1994) suggested that correction of the malocclusion in patients with open bite malocclusion will lead to elimination of abnormal swallowing. This finding was consistent with Cleall’s opinion (1965). Subtelny and Subtelny (1973) used a tongue crib to treat patients with tongue-thrust activities and found that while in place the tongue is confined lingually to the crib, but once the crib is removed, the protrusive tongue returned to the previous activity. In rare cases huge tongue size is the cause for the malocclusion; surgery is indicated in true macroglossia.

2.2.2.9. Tongue-thrust Summary

In summary, in most cases the tongue-thrust swallow appears not to be the primary aetiological factor in open bite malocclusions but rather an adaptive process. The correction of the malocclusion in most cases will lead to elimination of the thrust. However, tongue-thrust may be an important contributing and maintaining factoring to the open bite malocclusion. Tongue-thrust is an important factor in relapse after treatment, but there are additional factors involved in relapse such as unfavourable facial growth, abnormal tongue size and neurological deficits in the tongue position (Gellin, 1978). It appears that the abnormal tongue rest position may be an important aetiologic factor in the development of open bite malocclusion as it has a small prolonged force action that will lead to teeth movement.

2.3. Open Bite Malocclusion

In addition to different oral habits that may contribute to development of open bite malocclusion, there are other contributing factors that should be considered before treating a case of open bite malocclusion. These factors are important when making decisions regarding treatment and stability after treatment. Included in this list are abnormal tongue posture (tongue rest position), allergic rhinitis, mouth breathing and facial hyperdivergence (Cozza, Baccetti, Franchi, Mucedero, & Polimeni, 2005; Proffit, 2000; Vazquez-Nava et al., 2006)

2.4. Intraoral Appliances and Effects on Articulation (Speech Production)

Intra-oral appliances can cause perturbations in the oral cavity. These perturbations have significant effects on vowel and consonant production (McFarland, Baum, & Chabot, 1996). Subjects display different compensatory mechanisms to overcome these oral perturbations (McFarland et al., 1996). However, great variation can be seen between subjects in the manner of compensatory adaptation that they engage in (Baum & McFarland, 2000). The mechanism of adaptation of speech to oral perturbation is not fully understood. One of the important factors that has been proposed in the adaptation process is the sensory feedback to the brain from the different orofacial structures (Smith, 1992). Another important factor is that of auditory feedback (Osberger & McGarr, 1982).

The adverse effects of perturbation on speech are various in different speech productions. For example in the anterior palate region, the use of intra-oral appliances causes perturbations and more specifically greatly affects sibilant production (McFarland et al., 1996). As well, vowel production is usually affected slightly under perturbation in the oral cavity (Flege, Fletcher, & Homiedan, 1988; Fowler & Turvey, 1980). However, perturbations have greater effects on consonant production over vowel production as consonants require more articulatory precision than vowels (Flege et al., 1988). Some consonants (i.e., /s/) need even more production accuracy (precision) than others (Baum & McFarland, 1997). Speech compensation for vowels is quicker than that for consonants (McFarland & Baum, 1995). In some cases speech compensation in the presence of perturbation is neither immediate nor as complete as previously thought (Baum, McFarland, & Diab, 1996; McFarland & Baum, 1995). Jacobs et al. (2001) found that after 9 years of implant placement, 82% of patients have articulatory errors, in comparison to 52% of subjects with natural teeth, this finding was statistically significant. Heydecke, McFarland, Feinea and Lund (2004) found that fixed appliances caused more speech errors than removable appliances. The authors also found that the adaptation for the vowels was more immediate and complete than the adaptation for the consonants; this finding was consistent with previous reports from different researchers (Baum & McFarland, 1997; McFarland & Baum, 1995; McFarland et al., 1996).

2.4.1. Palatal Plate and Speech

Bäckman, Grevér-sjölander, Holm and Johansson (2003) and Bäckman, Grevér-Sjölander, Bengtsson, Persson and Johansson (2007) studied the effects of palatal plates on speech articulation. The palatal plate is similar to what was described by Castillo-Morales (1998). The authors used it in children with Down syndrome to stimulate tongue retraction. The plates are removable appliances. When a plate is inserted in the mouth, the anterior part of the tongue is stimulated with a ball or a bead that is placed behind the maxillary incisors. Its purpose is to stimulate the anterior part of the tongue and in turn to stabilize articulatory patterns of dento-alveolar consonant production. Another aim of the appliance is to train the tongue to try to achieve a retracted position through a bowl-shaped elevation at the border between the hard palate and the soft palate (Bäckman et al., 2003; Bäckman et al., 2007).

Bäckman et al. (2007) followed children with Down syndrome longitudinally from age 6 to 48 months. Palatal appliances were inserted for 5-30 min each day starting from 6 months. They found that there were positive effects of these appliances on occlusion and facial expression compared to a Down syndrome control group without the palatal plate intervention. Although there were no effects on tongue morphology, the palatal plate had positive effects on speech and facial expression. However, the facial expression and speech were assessed qualitatively by speech and language therapists and a phonetician and the authors did not describe whether they were blinded to the treatment used.

Carlstedt, Henningsson and Dahllof (2003) studied 20 children with Down syndrome longitudinally for over 4 years. The authors examined the effects of the palatal plate therapy on oral motor function, articulation and communication preferences. A total of 9 children received palatal plate therapy, while 11 children were age-matched as a control. They explained that after therapy, children who received the palatal plate had less tongue protrusion at non-speech time than the control group. An improvement was also found in orofacial function, speech articulation, tongue position and lip activity in the Down's syndrome children who had received palatal plate therapy in comparison to the control group. The authors qualitatively assessed those children to evaluate the clinical parameters. It would be beneficial to test an appliance similar to the palatal plate to establish whether it can reduce tongue-thrusting in children with this habit.

2.5. Cephalometric Findings in Individuals with Oral Habits

Using cephalometry, Moore and McDonald (1997) demonstrated that only dento-alveolar changes were seen in thumb-sucking habits. Afzelius-Alm, Larsson, Lofgren and Bishara (2004) studied lateral cephalograms of 50 children with prolonged thumb-sucking habits and found that the lower incisors were proclined rather than retroclined. A number of causes were proposed for lower incisor retroclination including tight lower lip, early loss of primary molars and the angle between the thumb and lower teeth. Cephalometry has been used in assessment of effectiveness of thumb-sucking habit-breaking and the dento-alveolar correction that usually occurs after the habit has been eliminated. In a longitudinal study, Cozza et al. (2006) found that subjects had an average overbite increase of 3.5mm after treatment using a modified quad-helix with a palatal crib appliance. It was suggested that the correction was mainly from retroclination of the maxillary and the mandibular incisors with extrusion of 1.5 mm of the maxillary teeth and extrusion of 1 mm in the mandibular incisors.

2.6. Methods to Study the Tongue

Many methods have been used by researchers to study the tongue and to measure its size and position relative to other orofacial structures. These methods include the following:

1. Direct measurement of the tongue dimensions from cadavers (Hopkin, 1967). This method provides the actual dimensions of the tongue but does not provide measurements of physiologic tongue movement during function.
2. Cephalometric approaches to assess the 2-dimensional size and position of the tongue either by using regular cephalograms or by special radioopaque materials that facilitate the demarcation of the tongue from different facial structures (Cohen & Vig, 1976; Engelke, Mendoza, & Repetto, 2006; Vig & Cohen, 1974). This method has difficulty in assessing tongue contour due to overlapping of anatomical structures and variability in defining the landmarks and obtaining the measurements.
3. Direct measurement using alginate impression (Takada, Sakuda, Yoshida, & Kawamura, 1980). This method is useful to obtain an indirect measurement of the tongue size but would not be helpful in measuring the tongue dimensions during function.
4. Magnetic Resonance Imaging is also used in studying the size of the tongue (Lauder & Muhl, 1991). It gives an excellent view of the different soft tissues of the oral cavity. However, the subjects need special positioning and they are placed in a huge magnetic field. The Magnetic Resonance Imaging machine is also expensive.
5. Cinefluorography has been used to study the orofacial region with good success. However, the use of this technique has a limitation as patients receive a high dose of radiation. Fujiki et al. (2004) studied morphological features in relation to tongue movement during swallowing of 10 female participants with anterior open bite and

compared them with a group of 10 female participants with normal overbite. They correlated the cephalometric morphological features with tongue movement during swallowing. Findings showed that there were significant correlations between tongue movement and skeletal morphological features. They argued that the tongue movement is an adaptation to the maxillofacial morphology.

6. Ohkiba and Hanada (1989) used electropalatography to study tongue rest position in children with unilateral cleft palate before and after expansion of the maxilla. They found that after expansion the tongue moved upward in position and was much closer to the palate than before treatment. Electropalatographic and cephalometric assessment were also used in patients with open bite malocclusion to study the tongue function, with some success (Cayley, Tindall, Sampson, & Butcher, 2000).
7. Real time ultrasound was also used to study the dynamic and static position of the tongue in relation to tongue function. Shawker and Sonies (1984) first used the ultrasound of the tongue. They employed a B-mode ultrasound scan to study the tongue function during speech in normal subjects and compared them with subjects with neurological disorders. Fuhrmann and Diedrich (1994) studied the tongue using a B-mode ultrasound and tried to link the results of tongue position during function and at rest to different types of malocclusions. They indicated that more research would have to be done in this area before it can be used in diagnosis and treatment for patients with malocclusion.

For the purpose of our study, ultrasound scanning of the tongue was used for the following:

- The tongue surface can be readily visible on the ultrasound screen.
- The tongue movement can be studied in real time motion.

- There are virtually no known side effects to the use of the ultrasound compared to other techniques, and hence the ultrasound can be applied to different subjects including children.
- The application of the ultrasound is relatively easy, quick and does not require any previous special preparation to the subjects.

2.7. Tongue Ultrasound

2.7.1. Ultrasound Definition

Ultrasound is defined as an ultra high-frequency sound wave originating from a piezoelectric crystal. The piezoelectric crystal has the ability to convert electricity to mechanical vibration, which can be converted to sound waves. Also the piezoelectric crystal can convert sound waves to electricity. Ultrasound waves are reflected from different objects and surfaces similar to the reflection of light waves from different objects. After receiving the reflected waves (echo) they are converted into electrical currents that are then converted into an image. The distance between the object and the crystal can be measured because the sound waves travel and will be reflected back to the crystal so that the time can be measured and then used for distance calculations. Many crystals are placed on the ultrasound transducer in order to capture different areas while displaying the image on the ultrasound screen. The density of the image produced depends on the density difference between the objects that the wave travels through. In the case of high image density, the image produced is clearer on the ultrasound screen than the low density images. High density images can be produced when the ultrasound waves travel through tissue to air or tissue to bone interface. For a tongue ultrasound, the tongue surface interface is clear on the ultrasound image because of the strong echo that is produced from different object densities i.e., tongue and air interface.

2.7.2. Two-Dimensional Ultrasound

The use of 2-dimensional ultrasound imaging to study the tongue position has been widely adopted among phonetic researchers as well as recently in the field of dentistry. In phonetic research this technique is useful to study the shape of the tongue during different speech sounds (Chiang, Lee, Peng, & Lin, 2003; Stone, Shawker, Talbot, & Rich, 1988). Many studies have used ultrasound imaging of the tongue to study tongue function, especially in swallowing of healthy subjects and patients who suffer from oral motor coordination problems (neurologically impaired patients) (Kenny et al., 1989; Kenny, Casas, & McPherson, 1989; Shawker, Sonies, Stone, & Baum, 1983; Shawker, Sonies, Hall, & Baum, 1984; Stone & Shawker, 1986) and in patients with tongue cancer (Bressmann, Uy, & Irish, 2005).

2.7.3. Scan Types

There are a number of types of ultrasound scanning. A-mode (Amplitude-mode) is the basic element of the different scan types. It has one crystal that emits and receives sound waves. In the real-time B-mode scan, the ultrasound transducer contains multiple piezoelectric crystals that emit and receive the sound waves. The computer in the ultrasound machine then converts these currents into an image showing the different objects on the ultrasound screen. During B-mode ultrasound scan most ultrasound machines produce 30 scans per second and hence the output of the real-time B-mode scan will be 30 video frames per second.

2.7.4. Advantages of Ultrasound

Much attention has been directed recently toward ultrasound imaging as a mean to study the tongue in Speech-Language Pathology research. The main advantages of ultrasound imaging are the ease of use, bio-safety and relatively low cost (Bressmann, Heng, & Irish, 2005). By using an ultrasound, almost any investigator can obtain the required image without the need for special training. The ultrasonographic recording of the tongue is non-invasive for the subject and does not require any preoperative instructions e.g., fasting. Recording involves placing the ultrasound transducer under the chin in the submental area with the possibility of using a head fixation mechanism to stabilize the head and transducer during the examination. Dynamic tongue movement and voice during function and at rest can be recorded in a video format and digital videos can be saved in a computer where they can be traced. These videos can be analysed using different computer software programs (Bressmann et al., 2005). The ultrasound recording of the tongue is non-invasive and convenient for adults and children with minimal or no discomfort. The ultrasound machine is light in weight, with virtually no space requirement and can be portable in nature (Bressmann et al., 2005).

2.7.5. Ultrasound Scan of the Tongue and Malocclusion

Fuhrmann and Diedrich (1994) used B-mode ultrasound scanning to study the midsagittal tongue surface in 60 subjects. Forty had abnormal swallowing or tongue movements and presented with different types of malocclusion. The authors compared these participants to 20 subjects with Angle class I occlusion who did not show signs of dysfunctional activity. They showed that the ultrasound can be a helpful adjunct for measuring tongue activity in different types of malocclusion, especially tongue-thrust activity. However, in their study, only qualitative measures were used to describe whether any swallow was normal or abnormal and they did not explain if the investigators were blinded to the type of occlusion. Peng, Jost-Brinkmann, Yoshida, Miethke and Lin (2003) used B and M-mode ultrasound of the tongue in subjects with infantile and mature swallowing. While it was not possible to differentiate between the mature swallow from the infantile type when examining the tongue dorsal surface, the movement of the genioglossus muscle was helpful in differentiation between the two swallows.

2.8. Aims of the Study

The aim of this pilot study was to compare, in children with reduced overbite malocclusions associated with oral habits (finger-sucking and tongue-thrusting), the effects of the experimental MFT and the conventional BG on dento-alveolar relations, on tongue position at rest and during physiologic movement, and on speech.

2.9. Specific Objectives

To examine both MFT and BG appliances for:

1. Efficacy of habit-breaking, confirmed by history and clinical assessment.
2. Dento-alveolar changes assessed by study models and cephalometric analyses.
3. Static and dynamic longitudinal changes in tongue position, analyzed by midsagittal 2-dimensional B-mode ultrasound scans.
4. Effects on speech acceptability.

3. Materials and Methods

The sample consisted of 8 subjects between the ages of 7-13 years. They were recruited from a private paediatric dental office in Ontario and from the Paediatric Dentistry Clinic at the Faculty of Dentistry, University of Toronto. All participants recruited for the study were fluent English speakers and had normal speech and hearing capabilities. Subjects were eligible for the study if they had an anterior open bite or reduced over bite malocclusion associated with oral habits i.e., non-nutritive sucking and tongue-thrusting, irrespective of the molar relationship. Eligibility was assessed by patient history and oral examination. The presence of an oral habit was verified by taking a patient and parent history. The oral examination consisted of a full orthodontic examination. The researcher diagnosed tongue-thrusting by observing the tongue position while he opened the lips of the subject while they were swallowing. Due to the anterior open bite malocclusion, 7 patients had a tongue-thrust swallow. A child was diagnosed with a tongue-thrust if no other associated habit was present. Informed consent was obtained from the legal guardian of each participant (Appendix I; informed consent). The study was approved by the ethics committee of the University of Toronto (Appendix II)

The subjects were divided into 2 groups: the first group used the Bluegrass (BG) appliance, while the second group used the pre-orthodontic Myofunctional Trainer appliance (MFT). The subjects were age and gender-matched but the process of assignment was not random. Diagnostic study models and pre-orthodontic cephalometric radiographs were taken. Extra-oral and intra-oral photographic series were obtained which included frontal views (teeth in occlusion and apart) along with right and left views with maximum intercuspation. The subjects were assessed before appliance insertion, immediately after appliance insertion (within 1 hour from appliance insertion), after 2 weeks from appliance insertion, and at the end of treatment (within 1 hour from appliance removal). Study models and cephalometric records were obtained during before and end of treatment examinations. Ultrasound and speech records were obtained during before, immediately after appliance insertion, after 2 weeks, and at the end of treatment examinations. However, for the MFT group speech and ultrasound records were not obtained immediately after appliance insertion as the subjects were not expected to talk with removable functional appliances in place.

3.1. The BG Appliance Group

Four subjects were recruited hereafter named: VP, MM, SE and PK. Two were females and 2 were males. All had finger-sucking habits except PK who had tongue-thrust habit. The subjects mean age was 11 years and 4 months with a standard deviation of 1.83 years and an age range of 8.9 to 13.2 years. Figures 1-4 show subjects in the BG group.

Figure 1. VP, 8.9 years

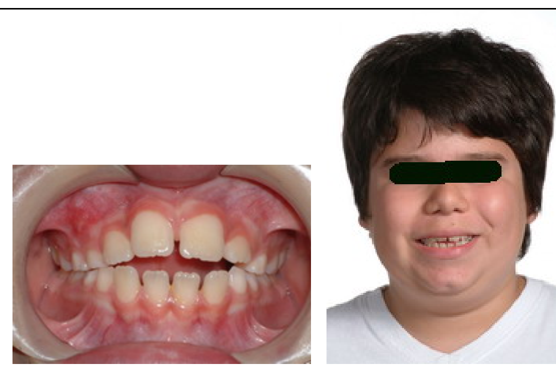


Figure 2. MM, 11.2 years

Figure 3. SE, 12.1 years

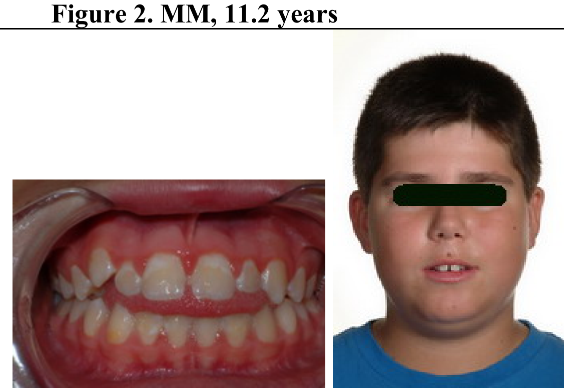


Figure 4. PK, 13.2 years

In the BG appliance group, working models were poured in stone and were sent to a lab (Canadian Orthodontics, Toronto, Ontario) for fabrication of the BG appliance (Figures 5, 6, 7). The BG appliance made for the study had the following components:

1. Bands on the maxillary first molars

2. A 0.045” or 0.036” stainless-steel wire: the wire extended anteriorly to the rugae of the anterior palate and posteriorly it attached to the molar bands (using a post and peg mechanism secured with a dead soft wire lock attachment). Wilson loops were added to the stainless-steel wire as seen in figure 6. The attachment method is different than that described by Haskell and Mink (1991) in which they had the wire soldered to the molar band. This modification was made to make any future adjustments of the appliance easy to perform.

3. A hexagonal Teflon roller (Figure 5): this roller was attached to the anterior aspect of the stainless-steel wire. The Teflon roller was placed away from the palate (Figure 7), and the child was instructed to play with the roller with the tip of his/her tongue instead of performing the oral habit. The appliance works as a physical obstruction to the tongue and reduces the pleasure of finger-sucking.

Figure 5. Bluegrass appliance on a stone model

Figure 6. Post and peg attachment on the molar band with locking wire.

Figure 7. The BG appliance in place after cementation

3.2. Pre-orthodontic MFT Appliance Group

Four subjects were recruited in this group hereafter named: MK, MR, OS and CE. Two were females and 2 were males. CE had both thumb-sucking and nail biting habits. MR and OS had finger-sucking habits. MK who had a tongue-thrust habit, provided the following description: ‘She liked to play with her tongue and place it between her teeth’. The subjects mean age was 10 years with a standard deviation of 2.6 years and age range of 7.6 to 12.7 years. Figures 8-11 show the subjects in the MFT group.

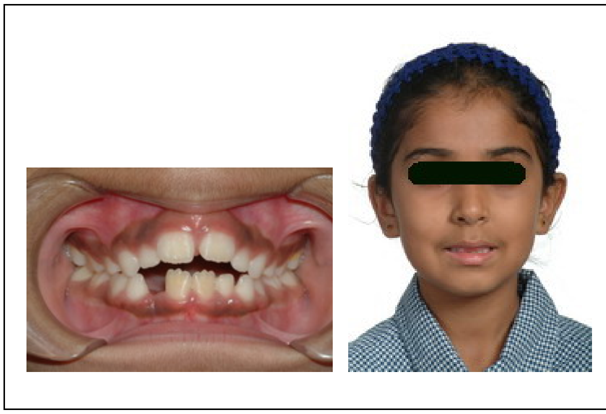


Figure 8. MK, 7.6 years

Figure 9. MR, 8;1 years

Figure 10. OS, 12;1 years

Figure 11. CE, 12;7 years

The MFT appliance is a removable appliance. It was developed by the Myofunctional Research Company in Australia. It comes as a prefabricated removable appliance. For children in the mixed dentition stage the company recommends the T4K appliance (Figures 12, 13).

Figure 12. Photograph of the pre-orthodontic trainer T4K (MFT appliance).

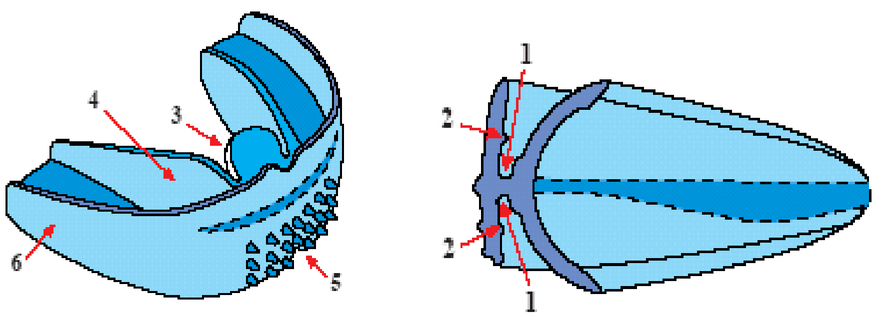


Figure 13. Different parts of the MFT appliance highlighting important aspects with numbers, 1. Tooth channels, 2. Labial bows, 3. Tongue tag, 4. Tongue guard, 5. Lip Bumper, 6. Buccal guard (adapted from Myofunctional Research Co. website).

All children in the MFT group received the T4K appliance. The T4K is prefabricated and thus only comes in one size. Subjects were instructed to place the appliance inside their mouths for at least one hour during the day and at night during sleeping every day. In addition, subjects were instructed to insert the appliance while they were at home, while they were engaged in television watching or doing their homework as much as possible. The subjects and their parents were given instructions on what might occur when the appliance was inserted in the mouth for the first time. They were informed that there would be an increased salivation and the appliance might fall from the mouth during sleep in the beginning, but after a period of time the child would grow accustomed to it. Also instruction about nose breathing during appliance wearing was given.

3.3. Clinical Criteria for Success of Habit-breaking

After insertion of the appliances, any history of habit-breaking was determined from both the participant and their parents to verify success of habit-breaking treatment. The participants were contacted and examined every 6-8 weeks. Success of a habit-breaking appliance was marked when the habit was eliminated. Partial success of treatment was marked when the habit was mostly reduced but the subject still sometime indulge in the habit or when there was some compliance issue with wearing the removable appliance. Failure of treatment was marked when the habit was not eliminated or reduced.

Proffit (2000) indicated that the habit-breaking appliance should remain in place for at least 6 months after habit cessation to insure that the habit had truly stopped even though cessation of the habit usually occurs within a few days after insertion of the appliance. The BG group participants were instructed to play with the Teflon roller instead of performing the habit and also to place the tongue behind the roller when swallowing so that the tip of tongue would be higher in position during the swallow and not to thrust between the anterior teeth. For the MFT group the recommendation made by the manufacturing company was to wear the appliance for 12 months and then evaluate habit-breaking and any favourable soft tissue changes. In our study clinical evaluation of favourable dento-alveolar changes i.e., open bite and overjet corrections were assessed at each follow-up visit for both groups and were also used to verify habit-breaking.

3.4. Cephalometry

Standardized orthodontic lateral cephalograms for the subjects in both groups were taken using the same cephalogram machine in the Faculty of Dentistry, University of Toronto. The lateral cephalometric radiographs were then traced by the same investigator (I.S) and the different cephalometric landmarks were reconfirmed with an instructor from the Department of Orthodontics, Faculty of Dentistry, University of Toronto. The University of Toronto regimen was chosen for cephalometric analysis, which includes 124 different landmarks on the paper tracing (Appendix III & IV). The tracings were then digitized using Dentofacial Planner software 1995 (Dentofacial Software Inc., Toronto, Ontario, Canada). The software was used to calculate measurements and angles between different landmarks. The software provided different angles and linear cephalometric measurements. Intra-rater reliability of cephalometric analysis was performed to test the reliability of the investigator in cephalometric tracing and digitization of landmarks. A paired *t* test was used to examine the differences between 2 different tracings and digitization that were performed on a different occasion. For angular measurements, the mean difference was 0.24º ± 1.5 (Mean difference ± SD), which was not significant ($P = 0.51$). For the linear measurements, the mean difference was 0.0083 mm ± 2.08, which was not significant ($P = 0.99$). The angles that were included in our cephalometric analysis were as follows: SNA, SNB, ANB, Upper 1 to SN, Lower 1 to MP, Y axis, Inter-incisal. The linear measurements that were analyzed included: MdLength (Cd-Gn), Mx Unit Length, Unit Difference, LFH (Sn'-Me), ULip to E Line, Lower Lip to E. For definition of the different landmarks and measurements see the following:

Cephalometric Landmarks

S: Sella, midpoint of the sella turcica.
N: Nasion, junction of the frontal and nasal bones at the naso-frontal suture.
A: A Point, deepest point in the concavity of the anterior maxilla between the anterior nasal spine and the alveolar crest.
B: B Point, deepest point in the concavity of the anterior mandible between the alveolar crest and pogonion.
Pogonion, most anterior point on the bony chin.
Cd: Condylion, most postero-superior point of the mid-planed contour of the mandibular condyle.
Gn: Gnathion, most antero-inferior point on the bony chin, located by bisecting mandibular and facial planes.
ANS: Anterior Nasal Spine, anterior limit of the floor of the nose, at the tip of the anterior nasal spine.
Me: Menton, most inferior point on the bony chin.
Porion: most superior point of the bony external auditory meatus.
Orbitale: most inferior point on the infra-orbital margin (mid-planed)

Cephalometric Measurements

SNA: angle formed by sella-nasion and A point
SNB: angle formed by sella-nasion and B point
ANB: difference between SNA and SNB
Upper 1 to SN: angle formed by the intersection of maxillary central incisor and SN line.
Lower 1 to MP: angle formed by the intersection of mandibular central incisor and mandibular plane.
Frankfurt horizontal plane: line from porion to orbitale.
Y axis: angle formed by intersection of sella-gnathion and the Frankfurt horizontal plane.
Inter-incisal: angle formed by the intersection of the maxillary central incisor and the mandibular central incisor
MdLength (Cd-Gn): measures the length of the mandible from condylion to gnathion.
Max Unit Length: maxillary unit length, measures the length from condylion to ANS (inferior point where ANS is 3mm thick)
Unit Difference: difference between the MdLength and Max Unit Length.
LFH: lower face height**,** measures the length from ANS (superior point where ANS is 3 m thick) to menton.
ULip to E Line: distance in mm between the upper lip and the E line (Esthetic line that connect the tip of the nose to the anterior point on soft tissue chin)
Lower Lip to E: distance in mm between the lower lip and the E line.

3.5. Study Model Analysis

Alginate impressions for the maxillary and mandibular arches were taken before and after treatment along with a wax bite registration in centric occlusion. These impressions then were poured in a white stone and were trimmed and articulated. Measurements of the dental arch parameter were performed directly from the dental casts using a caliper accurate to 0.1mm by the same investigator (I.S). Intra-rater reliability of model analysis was performed. A paired *t* test was performed to examine the differences between 2 separate study model measurements that were performed on a separate occasion. The mean difference between the first and second model measurements was 0.031 mm ± 0.38, which was non-significant (P = 0.65). Overjet was measured from the incisal edge of the most labially positioned maxillary central incisor to the labial surface of the mandibular central incisor. Overbite was taken as the vertical measurement of the overlap of the incisal edge of the maxillary central incisor and the incisal edge of the mandibular central incisor. Inter-molar cusp width was measured between the mesiobuccal cusps of the maxillary first molars. Inter-molar width was measured from the lingual groove of the maxillary first molar at the gingival level. Occlusion assessment was recorded using Angle's molar classification.

3.6. Qualitative Assessment of Aesthetics for Open Bite Correction

Clinical photos of the occlusion were taken before and after treatment for each subject. The photos included teeth in occlusion with frontal view, right side view and left side view. Also, facial profile photos were taken, but these were not included in the aesthetic evaluation.

Clinical photos of the anterior open bite correction were assessed before and after treatment. A total of 11 post-graduate dental speciality students between the ages of 27 to 35 years old rated the photos. The students were from different departments at the Faculty of Dentistry, University of Toronto. The clinical photos were presented to the rater with a visual basic program written in an Excel environment (Appendix V). The raters were asked to look at the computer screen and the clinical photos of the subject's occlusion were presented in that frame. The photos were rated according to the degree of open bite with the following scale: 1 = normal overbite, 2 = mild open bite, 3 = moderate open bite, 4 = severe open bite. In each frame there were 3 photos demonstrating the dentition in occlusion from different views (frontal view, right side view, left side view) for the same examination (before or after treatment) . The software program saved the score for each frame and all data was saved to an Excel spreadsheet. There were 8 subjects with before and after-treatment photos. Each set of 3 clinical photos was rated twice by the same rater. This provided a set of 32 frames for raters to provide scores for. The software program auto randomized the frames that were presented to be scored. The scores were averaged for each subject to give the final score.

3.7. Ultrasonographic Data Acquisition

3.7.1. Midsagittal B-Mode Ultrasound

Midsagittal, 2-dimensional B-mode ultrasound scans were used to conduct an ultrasound examination of the tongue surface for both groups. For the BG appliance group the following ultrasonographic examinations were conducted: before appliance insertion (baseline), immediately after appliance insertion (within 1 hour from appliance insertion), 2 weeks after insertion and at the end of the treatment (within 1 hour from appliance removal). For the MFT appliance group, ultrasonographic examinations were conducted before appliance insertion (baseline), two weeks after insertion and at the end of the treatment. The immediate examination was omitted because subjects could not speak while wearing the MFT appliance. The ultrasound machine used was a low-end General Electric Logic Alpha 100 MP. It had a 6.5 MHz micro convex-curved array scanner with a 114º view (Model E72, General Electric Medical Systems, Milwaukee, Wisconsin). The output of the ultrasound examination was recorded as a video format using a digital video camera (Canon ZR 45 MC, Canon Canada Inc., Mississauga, Ontario). Simultaneously, sounds were recorded on the same digital videotape using an AKG C420 headset condensator microphone (AKG Acoustics, Nashville, Tennessee) with a Behringer Ultragain Pro 2200 line-driver (Behringer Ltd., North Creek Pkwy, Bothell, Washington). The digital videos were then downloaded onto a computer where they were saved as digital video files (Windows Media Player, version 10).

During the ultrasonographic recording, subjects were seated and their head were stabilized by the Comfortable Head Anchor for Sonographic Examinations (CHASE) developed by Carmichael from the Institute of Biomaterials and Biomedical Engineering, University of Toronto, as shown in Figure 14. The transducer of the ultrasound machine was placed under the chin and attached to the CHASE. By reading text from a computer screen located in front of them, subjects then performed speaking tasks. The CHASE apparatus was modeled close to the device described by Peng, Jost-Brinkmann, Miethke and Lin (2000). The transducer was attached to the CHASE, and a subject was instructed to rest his/her head on the headrest. The CHASE is unable to fix the head position, but provides attachment to the ultrasound transducer which is placed under the chin and in turn stabilizes the head on the headrest.

The subjects were assisted in keeping their head in the correct position in relation to the transducer and the headrest. This position was maintained by gentle support of the head with the examiner's hand.

Figure 14. The subject is seated and the head is stabilized in the CHASE apparatus.

The readings involved reading of tongue twisters, a reading passage "Grandfather Passage" and pronunciation of different syllables that combined vowel-consonant-vowel (VCV) sequences e.g., /asa/, /ata/, /ese/, /ete/, /oso/, /oto. In addition, the participants performed swallowing tasks; dry swallows and a 10 ml water swallow. The vowels that were analyzed included; /a/, /i/, /u / as they represent the extreme tongue position for vowel articulation (Figure 15). The VCV non-sense syllables were repeated by the subject 5 times stressing the last vowel. Analyses of many of the VCV non-sense syllables, tongue twisters and the reading passage records were not included in this study. The ultrasound examination and the recording took approximately 10-15 minutes to perform.

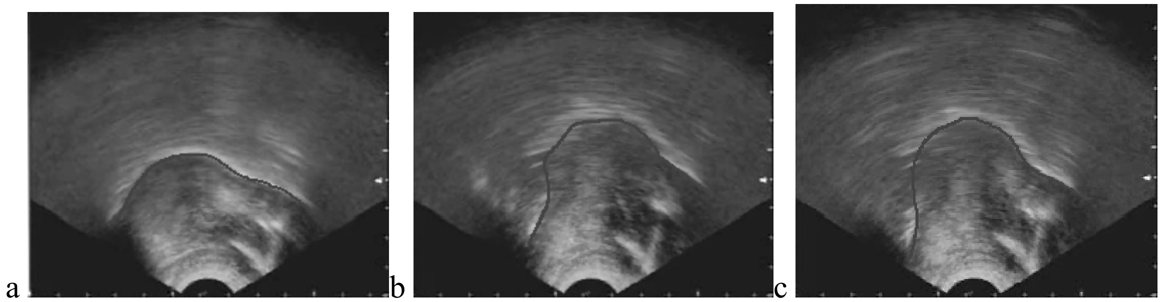


Figure 15. Midsagittal ultrasound view of the tongue showing tracing of the tongue surface during /a/, /i/, /u/ vowel production. The anterior tongue points to the right side of the images. a) Ultrasound image during /a/. b) Ultrasound image during /i/. c) Ultrasound image during /u/.
Bressmann, T. et al., 2005.

3.7.2. Data Management

3.7.2.1. Screenblast Movie Studio

The ultrasound videos were imported from digital camera videotapes and were saved as media files with .wmv format on the computer. Videos were then cut using Screenblast Movie Studio 3.0 (Sony media, Sony of Canada Ltd., Toronto, Ontario), which is a software to manage media files and produce short video clips. The VCV syllable movies were cut for each subject during different examinations e.g., before treatment, immediately after appliance. Movies for wet swallows were also cut in the same manner using the Screenblast Movie Studio.

3.7.2.2. Ultra-CATS Program

The Ultrasonographic Contour Analyzer for Tongue Surfaces (Ultra-CATS) software was used to analyze the short video clips. The Ultra-CATS program was developed for the Voice and Resonance Lab at the University of Toronto. The program shows different video frames of the ultrasound scans that were recorded (Figure 16).

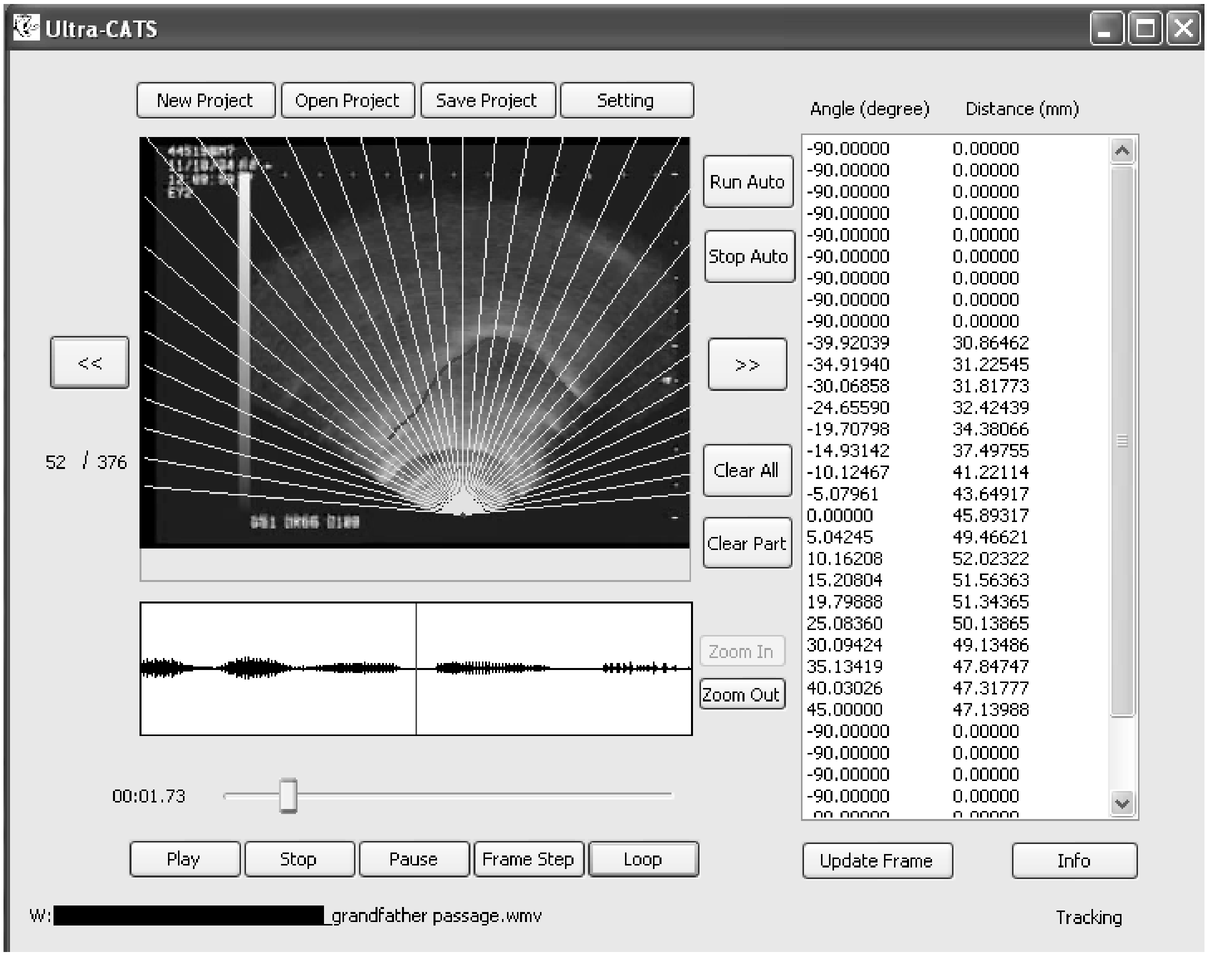


Figure 16. Ultra-CATS frame with tracing and the 5º grid

On each frame the investigator has the ability to trace the surface of the tongue. From here, the program will perform the necessary measurements from the transducer to the tongue surface. At the transducer point a grid of 5º radiate and the points of intersection with the tongue surface were measured (Figure 17). For each second of recording there were approximately 30 frames of output data. The Ultra-CATS produced the different measurements in mm to the nearest 2 decimal points. The program saved all measurements to a comma delimited text file to be analyzed using a spreadsheet editor. The different points on the tongue surface were coded from p85, p80, a75…..a75, a80, a85. In this description, 'p' stands for the posterior part of the tongue and ‘a’ stands for the anterior part of the tongue, while the number represent the angle formed by the grid on the tracing frame (Figure 17).

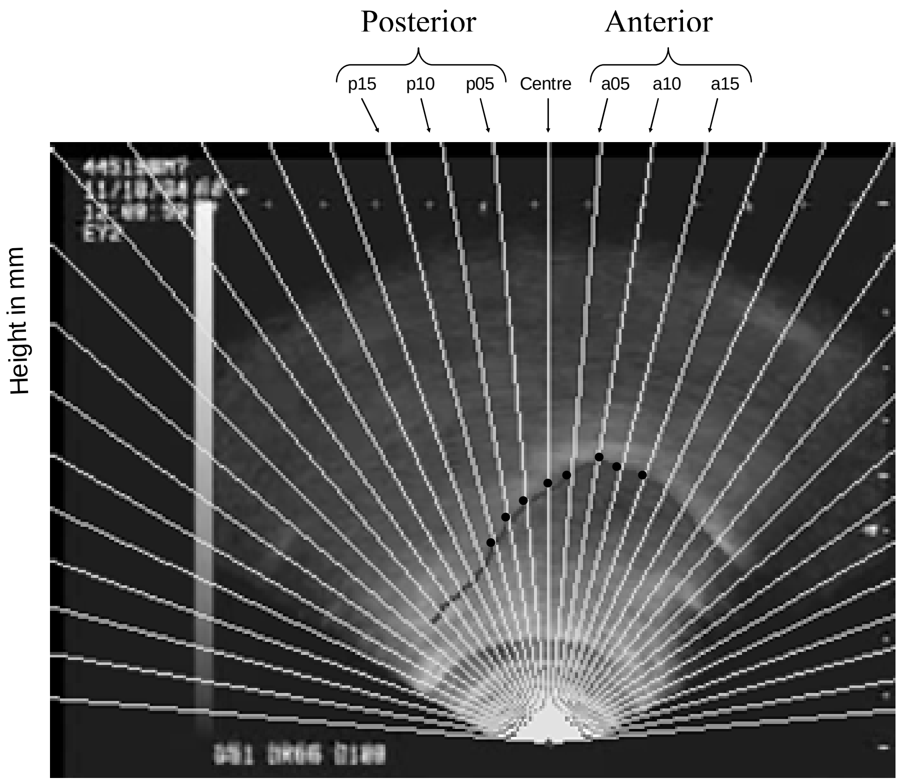


Figure 17. Ultrasound frame from the Ultra-CATS program showing different angles on a 5º grid that intersects with tongue tracing (black dots). ‘a’ denotes ‘anterior tongue’ , ‘p’ denotes ‘posterior tongue’.

3.7.2.3. Data Analysis for Tongue Position during Function

The following description outlines the method used to analyze tongue ultrasound data. The tongue heights in selected ultrasound frames were measured using the Ultra-CATS program. The frames were selected from different speech productions. The subjects were instructed to say different non-sense syllables VCV i.e., /asa/, /ata/, /ese/, /ete/, /oso/, /oto/, which were repeated at least 5 times. These VCV non-sense syllables were used for the analysis of the tongue during function. The second vowel in the VCV was used in this analysis since it is the stressed vowel. The tongue height data from the second vowel of the VCV production was grouped according to the vowel content so that the tongue height during /asa/ and /ata/ vowel production were grouped and averaged to give the resultant tongue height during /a/ vowel production. Similarly, the tongue heights during /ese/, /ete/ and /oso/, /oto/ vowel production were grouped and averaged to give the tongue height during /i/ and /u/ vowel production respectively. The vowels /a/, / i/ and /u/ represent the phonetic alphabet. The analysis of the tongue position during function was performed for each subject individually. Tongue height measurements were averaged to the nearest one decimal point.

After the averages were calculated, tongue heights were compared at the following examinations: before treatment (baseline), immediately after appliance insertion, 2 weeks after insertion and at the end of treatment. In order to compare different examinations, the difference between tongue height in a particular examination and the baseline were calculated and the net difference was rounded to the nearest integer. A 5 mm difference was used as a cut-off to determine the net increase or decrease in tongue height and this was indicated as a single arrow. When more than a 7 mm difference was calculated, the difference was marked as a double arrow. Horizontal arrows indicated no large difference in tongue height noticed between different examinations. The ultrasound data were analysed with a semi-quantitative method to produce tables that showed the relative increase or decrease in tongue height during different examinations. These tables were found to be reproducible when the measurements were repeated.

3.7.2.4. Data Analysis for Tongue Rest Position

The method previously employed for the analysis of the tongue position during function was used to study the position of the tongue at rest for each subject. Wet swallow movies were used to obtain the rest position of the tongue. The subjects were instructed to swallow 10 ml of water while the ultrasound scan of the tongue movement was recorded in video format. Most of the subjects had a total of 5 wet swallows. The tongue rest position frames were defined as the frames after the wet swallow where the tongue is not moving. The frames were then traced using the Ultra-CATS program and the measurements of the tongue heights calculated. At least 5 frames were traced for each examination and the data obtained was averaged and recorded in the same method that was used in the analysis of tongue position during function (section 3.7.2.3).

3.8. Speech Acceptability Test

Speech acceptability is defined as the degree of “bizarreness” of phonetic realization and indicates the pleasantness of the speech of the person (Bressmann, Ackloo, Heng, & Irish, 2007). After the ultrasound examination, speech acceptability recording was performed for the subjects using the Computerized Test of Children’s Speech (TOCS+) program. This program contains multiple computer screens in which different words and sentences are shown with simultaneous pictures that describe the picture or the situation of the sentence (Appendix VI). The participant then said the word or sentence while it was being recorded in the computer as a sound file. Finally, a recording of participant’s spontaneous speech was obtained. This was achieved by having the participant tell a story or talk about a television program he/she had recently watched. For the BG appliance group the speech acceptability tests were performed: before appliance (baseline), immediately after appliance insertion, 2 weeks after appliance insertion and at the end of treatment. In comparison, for the MFT appliance group no speech test was done immediately after insertion of the appliance because the subjects could not talk while the appliance was inside the mouth.

Sound files that were recorded in a wave format were then embedded in an Excel spreadsheet (Appendix VII). Three sentences were randomly chosen from the sentences that the participant had recorded at each examination. Native English language speakers were recruited from the Faculty of Dentistry, University of Toronto to listen and rate the different sound files. For all of the listeners, English was their first language. They did not report any hearing problems, did not know the subjects and had not been involved in the treatment of the subjects previously. A total of 14 listeners were recruited with an age range of 27 to 47 years of age. Nine listeners were females and 5 were males (11 dentists and 3 supporting staff). The listeners were instructed to play the sound files and rate them from 0 to 3 for subject speech acceptability according to the acceptability score provided. The speech acceptability score had the following criteria:

0 = completely acceptable speech

1 = mildly affected speech

2 = moderately affected speech

3 = severely affected speech

The sound files that contained different sentences were randomly ordered in the Excel spread sheet and then divided into 4 spread sheets. The 4 spread sheets were numbered from 1 to 4. Each listener was given a different sequence of sheets e.g., the first listener would have the sequence of 1→2 →3→ 4 of the four Excel sheets, in contrast the second listener would have 2→1→4→ 3. This was done to control for order effects. The listeners were able to play the sound file repeatedly. An average of the 3 ratings taken from each individual listener was calculated for each examination. An average from all listeners was then taken from each particular examination to form the acceptability score.

3.9. Statistical Analysis

Data obtained from cephalometric measurements and study model were compiled onto SAS (version 9.1 for Windows) software program. The data obtained from aesthetic evaluation of open bite reduction and speech acceptability test were compiled onto SPSS (version 14) program. Descriptive statistics were run for both groups. Paired *t* tests for cephalometric and study models data were used to compare before and after treatment for subjects within the same group. Unpaired *t* tests were used to make comparisons between the groups. However, the non-parametric Wilcoxon signed ranks test was used to analyze the data obtained from aesthetic evaluation of open bite correction and the speech acceptability data. Cephalometric and study model measurements, and aesthetic evaluation scores at baseline were compared to those after treatment. Speech acceptability scores were compared to baseline at 3 time points (immediately after insertion, 2 weeks after insertion, and at the end of treatment). Ultrasound data were analysed with a semi-quantitative method to produce tables that showed the relative increase or decrease in tongue height during different examinations. Significance was set at 5%. However, given the small sample size of this study, results were also assessed at a 10% level.

4. Results

Results are presented for individual subjects first and summarized by the two groups later.

4.1. Study Subject MM

Subject MM had a thumb-sucking habit. The BG appliance was inserted when the subject was 11 years and 2 months of age. The treatment duration was 8 months and 22 days (264 days). MM did not have any complaints regarding the appliance during the treatment period except for some mild discomfort during eating and while speaking at the start of treatment. The thumb-sucking habit was successfully eliminated. It was noticed that the open bite was quickly reduced after insertion of the BG appliance and a positive overjet was achieved at the end of treatment.

4.1.1. Cephalometry

The pre-treatment cephalometric analysis showed that subject MM had an SNA angle of 92.3° and an SNB angle of 85.9°. On removal of the BG appliance, the SNA angle decreased to 90.4° while the SNB angle decreased to 83.3°. The upper incisor to SN (Sella Nasion plane) angle was reduced from 119.2° to 109.4°. In addition, the lower incisor to MP (Mandibular Plane) decreased from108.3° to 96.7°. The pre-treatment LFH was 66.8 mm which increased to 67.8 mm post-treatment. The upper lip to E line was reduced from 3.7 mm to 2.2 mm and the lower lip to E line decreased from 7.9 mm to 6.5 mm (Tables 1 and 2). Standard measurements for age shown in the tables were obtained from the Dentofacial Planner program database.

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
SNA	92.3	90.4	81.2 ± 3.3
SNB	85.9	83.3	77.3 ± 2.7
ANB	6.4	7.1	3.9 ± 2.1
Upper 1 to SN	119.2	109.4	102.0 ± 2
Lower 1 to MP	108.3	96.7	91.4 ± 3.8
Inter-incisal Angle	102.4	124	127.1 ± 9.7
Y Axis	58.5	56.8	59.4 ± 3.8

Table 1. Cephalometric angular measurements for subject MM.

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
MD Length	113.2	117.6	107.0 ± 4.4
Mx Unit Length	97.1	101.7	87.0 ± 3.4
Unit Difference	16.1	16.0	20.0
LFH	66.8	67.8	62 ± 4.3
Ulip to E line	3.7	2.2	0.0 ± 0.0
Lower Lip to E	7.9	6.5	-2.4 ± 2.0

Table 2. Cephalometric linear measurements (mm) for subject MM.

4.1.2. Study Models

The pre-treatment orthodontic models for subject MM showed a 3 mm open bite between the maxillary and the mandibular incisors. At the end of treatment the open bite was eliminated and a positive overbite of 2 mm was achieved. The result was a total open bite reduction of 5 mm. The overjet of 3 mm did not change at the end of treatment. Inter-molar cusp width was 52 mm before treatment. This increased by 1 mm at the end of the treatment. The pre-treatment molar relationship was class I on both sides. This molar relation became ½ cusp Class II on the left side and Class I on the right side at the end of treatment. Measurements from study model analysis are shown in the table below (Table 3).

Measurement	Pre-treatment	Post-treatment
Overjet	3 mm	3 mm
Overbite	-3 mm (open bite)	+2 mm
Inter-molar cusp width	52 mm	53 mm
Inter-molar width	34 mm	35 mm
Molar relationship	Class I both sides	½ cusp Class II left, Class I right

Table 3. Study model analysis for subject MM.

4.1.3. Clinical Photographs

Aesthetic evaluation of open bite reduction for each subject was performed using the scale that was described earlier in the materials and methods section (page 42).

The mean score before treatment for subject MM was 3.36 ± 0.58 (Mean ± SD). After treatment the mean score was reduced to 1.05 ± 0.213. There was a significant reduction in the open bite score ($P < 0.001$) as shown in the clinical photographs below.

MM Before Treatment

MM After Treatment

4.1.4. Tongue Ultrasound Analysis

4.1.5. MM Tongue Function Analysis

4.1.5.1. MM Tongue Height during /a/ Vowel Production

Immediately after appliance insertion, the anterior part of the tongue (centre to a30) (Tables 4, 5) was elevated with a depression of the posterior part in comparison to measurements at baseline. At the 2 week examination, the tongue height was similar to that measured at the end of treatment, even though the posterior part of the tongue (p30 to p10) was more depressed at the end of treatment (Tables 4, 5; Figure 18).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	45.8	46.5	47.1	47.4	47.5	47.2	46.5	45.8	45.1	44.9	44.6	44.5	44.7
Immediately After	39.8	42.0	44.3	46.2	48.1	49.8	51.3	52.7	54.1	55.3	56.4	57.0	57.9
2 Weeks After	39.7	40.9	41.9	42.9	44.1	45.0	45.6	46.4	46.9	47.6	48.2	49.2	50.6
End of Treatment	37.2	38.5	40.0	41.1	42.5	43.5	44.6	45.7	46.6	47.3	48.1	49.2	50.4

Table 4. Mean tongue height (mm) for subject MM during /a/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↓	↓	↔	↔	↔	↔	↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
2 weeks to Before	↓	↓	↓	↓	↔	↔	↔	↔	↔	↔	↔	↑	↑
End to Before	↓↓	↓↓	↓↓	↓	↓	↔	↔	↔	↔	↔	↔	↑	↑

Table 5. Relative increase or decrease in tongue height for subject MM during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

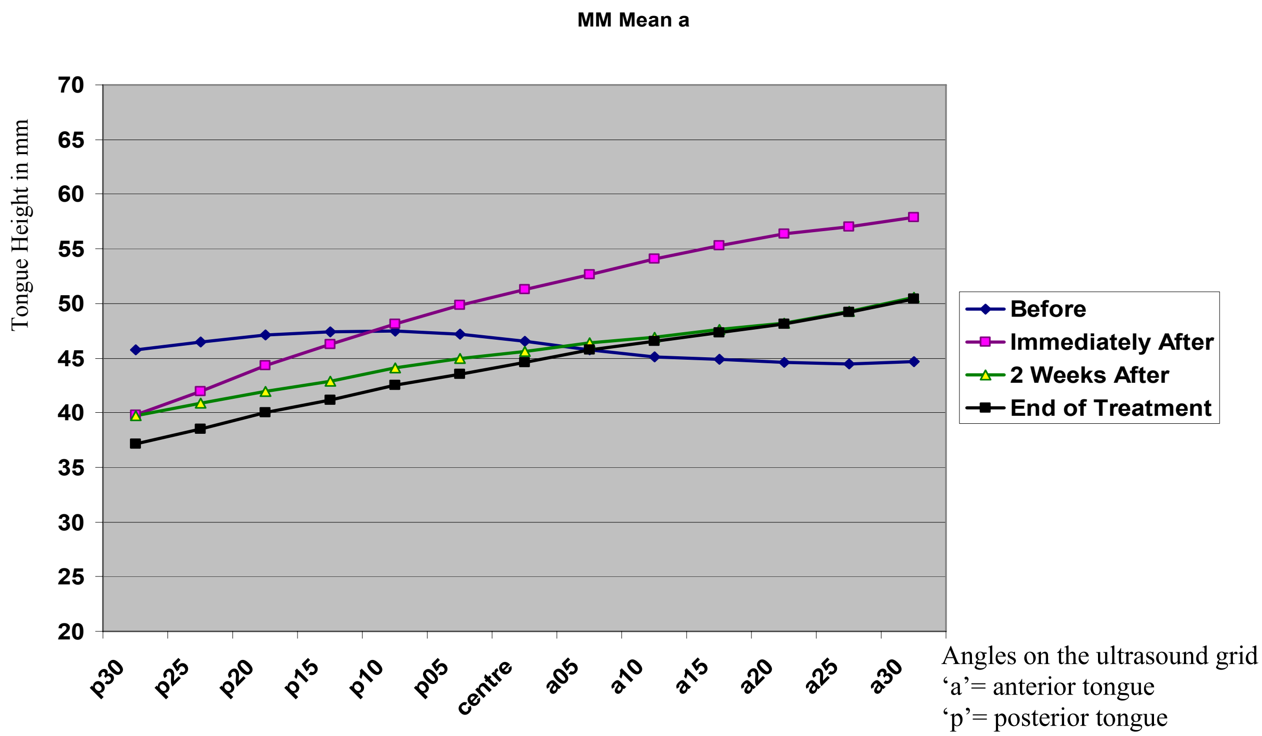


Figure 18. Mean tongue height (mm) for subject MM during /a/ vowel production at different examinations.

4.1.5.2. MM Tongue Height during /i/ Vowel Production

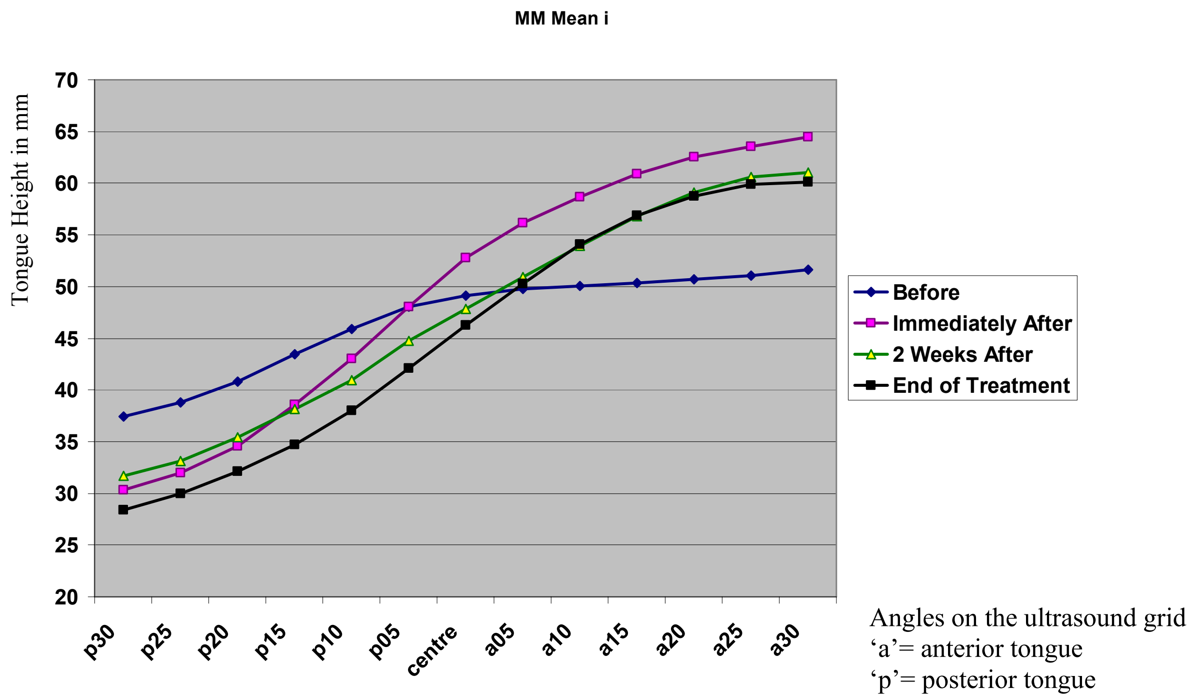
As indicated in tables 6 and 7, immediately after appliance insertion the anterior part of the tongue (a05 to a30) was elevated and there was depression of the posterior part of the tongue (p30 to p15), in comparison to baseline. After 2 weeks and at the end of treatment examinations, increased depression was noticed in the posterior part of the tongue (p30 to p05) while the anterior part of the tongue (a15 to a30) remained elevated (Tables 6, 7; Figure 19).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	37.4	38.8	40.8	43.5	45.9	48.1	49.1	49.8	50.0	50.4	50.7	51.1	51.7
Immediately After	30.3	32.0	34.5	38.5	43.0	48.1	52.8	56.2	58.7	60.9	62.5	63.5	64.5
2 Weeks After	31.7	33.2	35.4	38.1	41.0	44.8	47.8	50.9	53.9	56.8	59.1	60.6	61.1
End of Treatment	28.4	30.0	32.1	34.7	38.0	42.1	46.3	50.3	54.1	56.9	58.8	59.9	60.1

Table 6. Mean tongue height (mm) for subject MM during /i/ vowel production in different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	P30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↓↓	↓↓	↓	↓	↔	↔	↔	↑	↑↑	↑↑	↑↑	↑↑	↑↑
2 weeks to Before	↓	↓	↓	↓	↓	↔	↔	↔	↔	↑	↑↑	↑↑	↑↑
End to Before	↓↓	↓↓	↓↓	↓↓	↓↓	↓	↔	↔	↔	↑↑	↑↑	↑↑	↑↑

Table 7. Relative increase or decrease in tongue height for subject MM during different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.



.Figure 19. Mean tongue height (mm) for subject MM during /i/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

4.1.5.3. MM Tongue Height during /u/ Vowel Production

During /u/ vowel production, the anterior part of the tongue (a15 to a30) was elevated and the posterior part of the tongue (p30 to p10) was depressed at the examination immediately after appliance insertion. At the 2 week examination the height of the tongue was close (near) to the height at the end of the treatment where the posterior part of the tongue (p30 to p05) was depressed with elevation of the anterior part (a20 to a30) (Tables 8, 9; Figure 20).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	41.0	42.4	44.4	47.0	48.9	50.5	51.4	51.5	50.9	50.6	49.9	49.2	48.5
Immediately After	33.8	35.7	38.2	41.2	44.4	47.6	50.5	52.7	55.1	57.3	59.1	60.5	62.2
2 Weeks After	32.7	35.0	38.2	41.8	45.2	48.0	50.0	51.5	52.6	53.4	54.2	55.1	56.8
End of Treatment	32.0	33.9	36.4	39.1	42.2	45.6	48.7	51.0	52.9	54.2	54.9	55.2	54.6

Table 8. Mean tongue height (mm) for subject MM during /u/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post- Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↓↓	↓↓	↓	↓	↓	↔	↔	↔	↔	↑↑	↑↑	↑↑	↑↑
2 weeks to Before	↓↓	↓↓	↓	↓	↔	↔	↔	↔	↔	↔	↔	↑	↑↑
End to Before	↓↓	↓↓	↓↓	↓↓	↓↓	↓	↔	↔	↔	↔	↑	↑	↑

Table 9. Relative increase or decrease in tongue height for subject MM during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

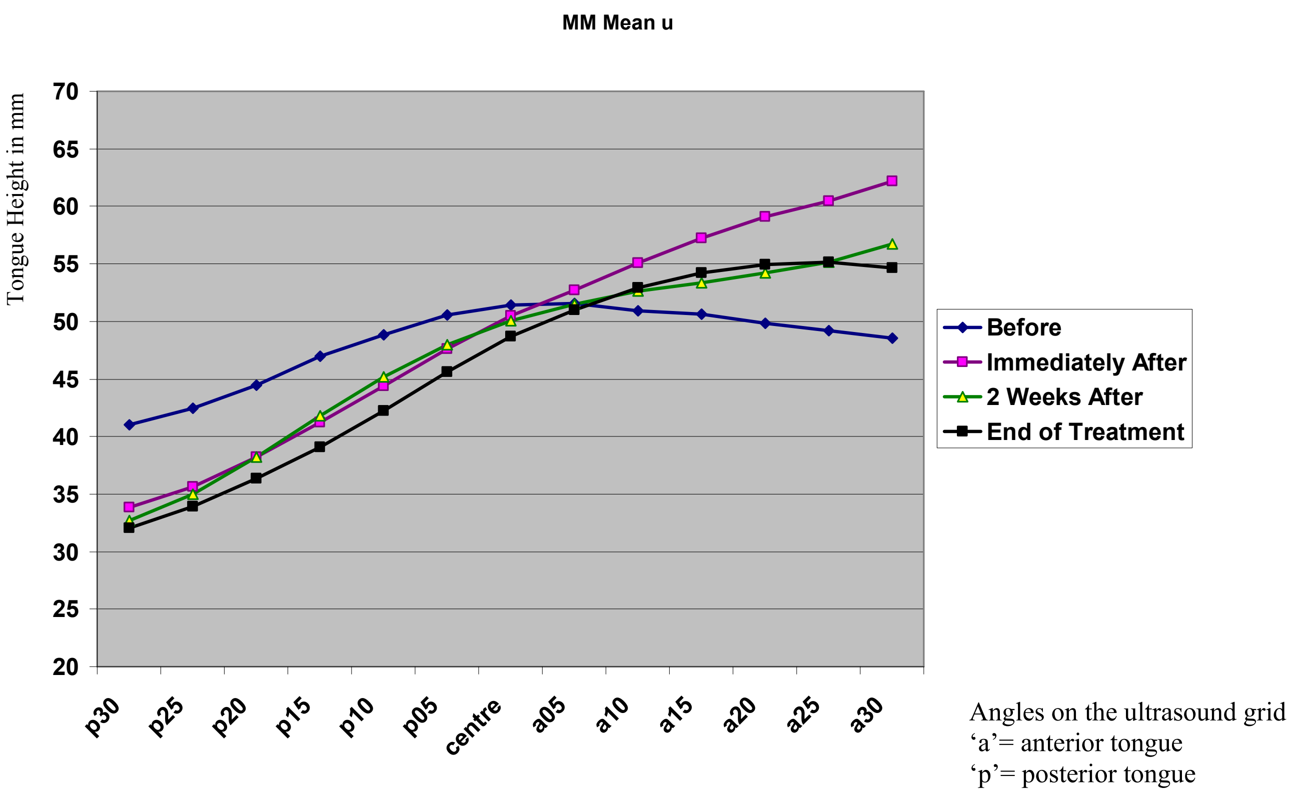


Figure 20. Mean tongue height for subject MM during /u/ vowel production at different examinations.

4.1.6. MM Tongue Rest Position Analysis

Immediately after BG appliance insertion examination showed that the only change in tongue rest position was the in posterior part of the tongue (p40 to p20), which was lower compared to baseline. Two weeks after insertion, the anterior and middle parts of the tongue (p05 to a40) were higher in position compared to their pre-treatment position while the posterior part of the tongue (p40 to p30) remained lower in position. At the end of treatment, the middle and anterior part of the tongue (p20 to a40) returned to baseline level. Meanwhile the posterior part of the tongue (p40 to p25) remained lower in position (Tables 10, 11; Figure 21).

	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Before BG	48.1	48.7	49.3	50.1	50.5	51.0	51.0	51.2	51.1	51.2	51.3	51.4	51.8	52.3	52.7	53.0	53.3
Immedia-tely After	39.9	41.2	42.5	44.1	45.8	47.4	49.0	50.6	52.0	53.1	53.7	54.0	54.2	54.2	55.1	55.6	56.0
2 Weeks After	39.0	40.8	43.3	45.7	49.0	52.0	54.4	56.2	57.2	58.2	59.1	59.7	60.3	60.9	61.4	62.0	61.4
End of Treatment	40.7	42.1	43.7	45.3	47.1	48.9	50.6	51.6	52.5	53.3	54.2	55.2	55.7	56.1	56.6	57.0	57.5

Table 10. Mean tongue height (mm) at rest for subject MM. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post-Pre	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	A35	a40
Immediate to Before	↓↓	↓↓	↓↓	↓	↓	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
2 Weeks to Before	↓↓	↓↓	↓↓	↔	↔	↔	↔	↑	↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
End to Before	↓↓	↓↓	↓	↓	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 11. Relative increase or decrease in tongue height for subject MM at rest during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

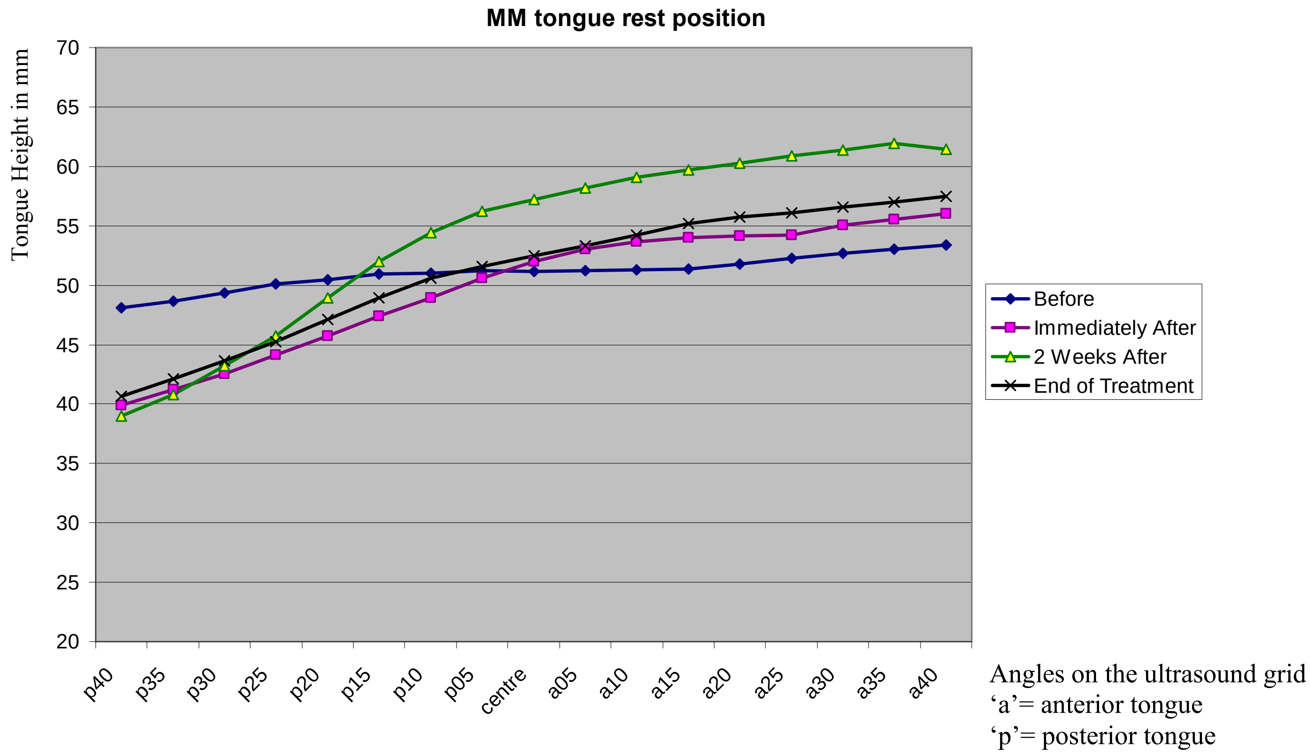


Figure 21. Mean tongue height at rest for subject MM during different examinations.

4.1.7. Speech Acceptability

The speech acceptability test was performed using the scoring method that was described earlier in the materials and methods section (page 50). Wilcoxon signed ranks test was used to test for statistical significance. The mean speech acceptability score for subject MM was 0.76 ± 0.98 (Mean score ± SD) prior to appliance insertion. This score increased to 2.79 ± 0.47 immediately after insertion of the BG appliance with a mean difference (Before – After) of -2.02 and a SD of 1.18. This increase in acceptability score immediately after appliance insertion was significant compared to the baseline score (P< 0.001). After 2 weeks of treatment, the score was reduced to 1.98 ± 0.92 with a mean difference of -1.21 ± 1.52 this showed a significant increase compared to baseline score (P < 0.001). At the end of treatment the score was 1.43 ± 0.63 with a mean difference of -0.67 ± 1.12, which showed a significant increase compared to baseline score (P = 0.001; see figure 22).

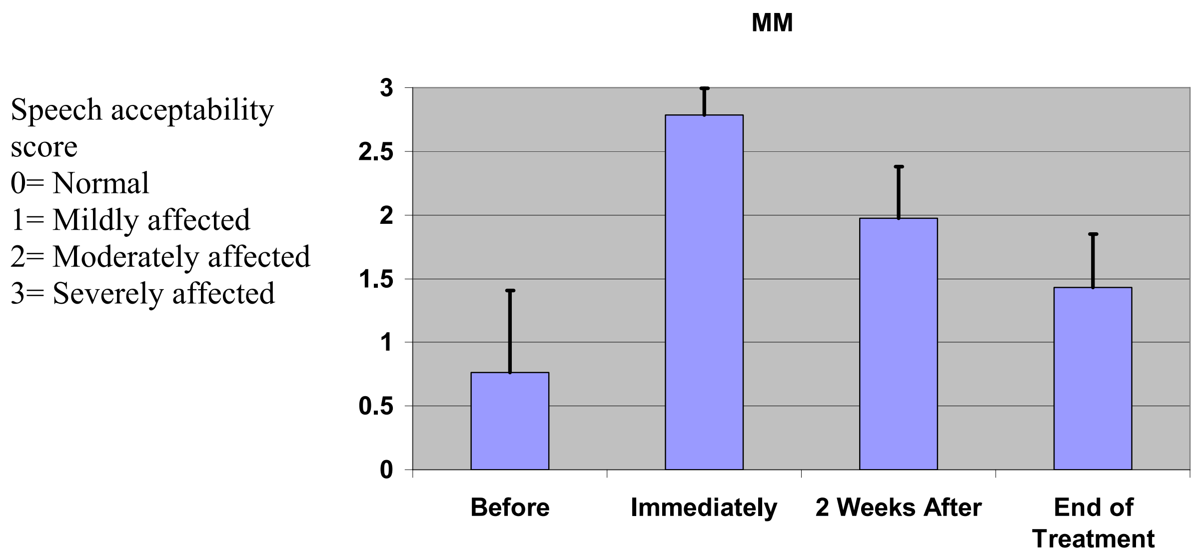


Figure 22. Mean Speech acceptability scores for subject MM during different examinations.

4.2. Study Subject PK

Subject PK had a tongue-thrusting habit. The BG appliance was inserted when he was 13 years 2 months of age. The treatment duration was 5 months and 8 days (159 days). After appliance insertion, PK indicated that the appliance had affected his speech and reported some speech adaptation over time. Although there was small improvement in the open bite, the BG appliance was not successful in breaking the tongue-thrusting habit and a decision was made to abort the treatment after consultation with the patient, parent and orthodontic staff. Thereafter, PK received a bonded rapid palatal expansion with a crib appliance to break the tongue-thrust habit and achieve maxillary expansion.

4.2.1. Cephalometry

The pre-treatment cephalometric analysis showed that subject PK had an SNA angle of 79.0° and an SNB angle of 80.0°. After removal of the BG appliance, the SNA angle increased to 84.4° while there was only a minimal change in the SNB angle at the end of treatment. The upper incisor to SN angle was 111.2° and at the end of treatment this angle was 112.4°. Minute changes were noticed in the inter-incisal and lower 1 to MP angles at the end of treatment. The LFH changed from 77.7 mm pre-treatment to 79.3 mm post-treatment. The upper lip to E line had changed from -2.8 mm to -2.4 mm and the lower lip to E was reduced from 4.1 mm to 2.8 mm (Tables 12 and 13).

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
SNA	79.0	84.4	81.2 ± 3.3
SNB	80.0	80.7	77.3 ± 2.7
ANB	-1.1	3.8	3.9 ± 2.1
Upper 1 to SN	111.2	112.4	102.0 ± 2
Lower 1 to MP	98.9	97.8	91.4 ± 3.8
Inter-incisal angle	112.8	112.5	127.1 ± 9.7
Y Axis	59.9	59.7	59.4 ± 3.8

Table 12. Cephalometric angular measurements for subject PK.

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
MD Length	128.6	132.7	114.0 ± 4.9
Mx Unit Length	91.8	100	92.0 ± 3.7
Unit Difference	36.8	32.7	22.0
LFH	77.7	79.3	64 ± 4.6
Ulip to E line	-2.8	-2.4	0.0 ± 0.0
Lower Lip to E	4.1	2.8	-2.8 ± 2.0

Table 13. Cephalometric linear measurements (mm) for subject PK.

4.2.2. Study Models

The pre-treatment orthodontic study models for subject PK showed that there was a 1 mm open bite between the maxillary and the mandibular incisors. At the end of the treatment the open bite was reduced to 0.5 mm. The initial overjet was 4 mm and at the end of the treatment it was 3 mm. PK had a super class I molar relationship on both sides before treatment. This molar relationship did not change at the end of treatment. Inter-molar cusp width was 57 mm before treatment that became 60 mm post-treatment (Table 14).

Measurement	Pre-treatment	Post-treatment
Overjet	4 mm	3 mm
Overbite	-1 mm (open bite)	-0.5 mm (open bite)
Inter-molar cusp width	57 mm	60 mm
Inter-molar width	40 mm	42 mm
Molar relationship	Super Class I both sides	Super Class I both sides

Table 14. Study model analysis for subject PK.

4.2.3. Clinical Photographs

The mean aesthetic score before treatment for subject PK was 3.14 ± 0.47. After treatment the mean score was decreased to 2.59 ± 0.59. There was a significant reduction of open bite score (P = 0.001) as perceived by the raters. See clinical photographs below.

PK Before Treatment

PK After Treatment

4.2.4. Tongue Ultrasound Analysis

4.2.5. PK Tongue Function Analysis

4.2.5.1. PK Tongue Height during /a/ Vowel Production

Immediately after insertion of the BG appliance, the anterior part of the tongue (a10 to a20) was depressed. Two weeks after treatment was started, the anterior part of the tongue (a10 to a30) was depressed further. In comparison, the posterior part of the tongue (p25 to p05) was elevated at the end of treatment (Tables 15, 16; Figure 23).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	46.5	47.5	48.6	49.4	50.2	50.8	51.6	52.4	53.1	53.7	54.2	54.6	55.2
Immediately After	44.8	46.3	47.6	48.5	49.0	48.9	48.7	48.5	48.6	48.8	49.7	50.6	51.9
2 Weeks after	46.2	47.4	48.4	48.7	48.8	48.5	48.4	48.6	48.4	48.1	47.9	47.8	47.5
End of Treatment	50.8	52.1	53.8	55.1	55.9	55.8	55.5	54.7	53.3	51.9	50.7	50.2	50.5

Table 15. Mean tongue height (mm) for subject PK during /a/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↓	↓	↓	↔	↔
2 weeks to Before	↔	↔	↔	↔	↔	↔	↔	↔	↓	↓	↓	↓↓	↓↓
End to Before	↔	↑	↑	↑	↑	↑	↔	↔	↔	↔	↔	↔	↓

Table 16. Relative increase or decrease in tongue height for subject PK during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

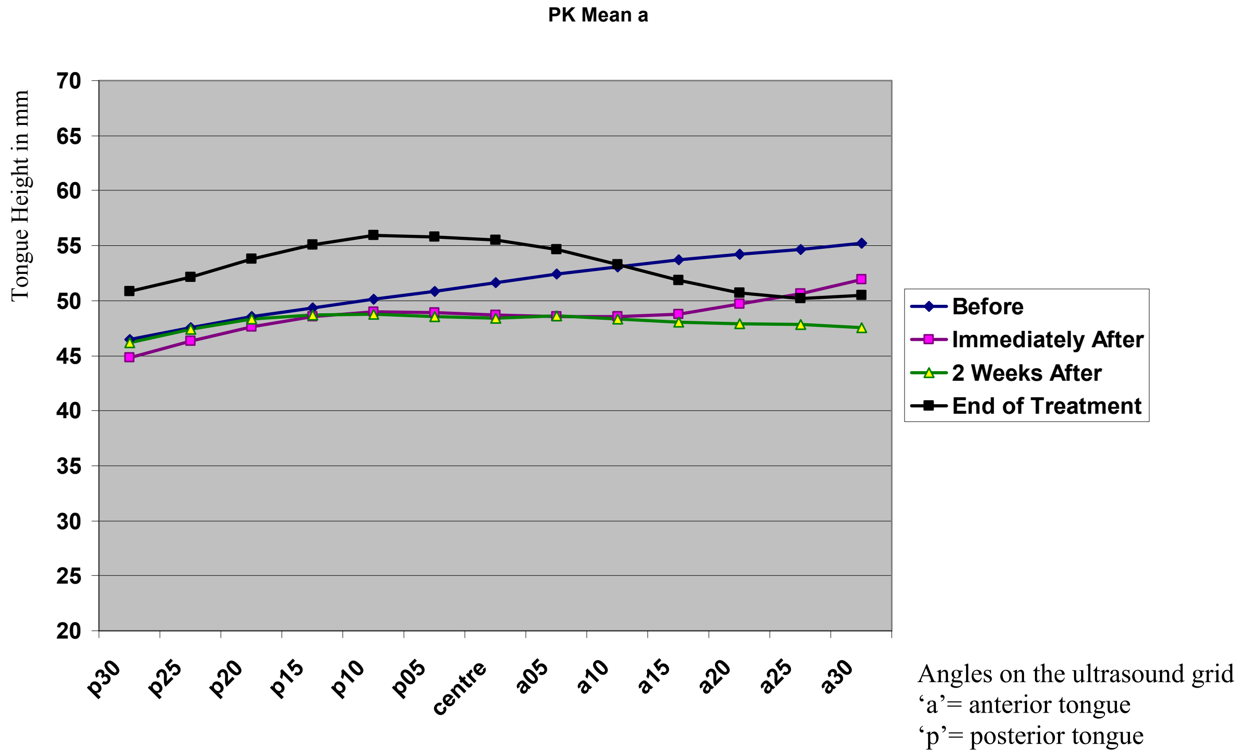


Figure 23. Mean tongue height for subject PK during /a/ vowel production at different examinations.

4.2.5.2. PK Tongue Height during /i/ Vowel Production

During /i/ vowel production, no large differences in tongue heights were found between the different examinations except at the end of treatment where the posterior part of the tongue (p30 to p20) was depressed (Tables 17, 18; Figure 24).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	35.0	36.7	39.1	42.2	46.4	51.0	55.4	59.1	61.6	62.6	62.0	61.0	59.5
Immediately After	30.6	33.2	36.3	40.1	44.9	48.9	52.6	56.1	58.8	60.1	60.2	58.8	56.4
2 Weeks after	32.3	34.3	36.6	39.8	43.8	48.8	52.5	55.1	57.1	58.2	58.1	57.7	56.7
End of Treatment	30.2	32.1	34.4	38.1	43.2	50.6	58.0	63.1	65.1	65.0	63.6	61.7	59.2

Table 17. Mean tongue height (mm) for subject PK during /i/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
2 weeks to Before	↔	↔	↔	↔	↔	↔	↔	↔	↓	↔	↔	↔	↔
End to Before	↓	↓	↓	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 18. Relative increase or decrease in tongue height for subject PK during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

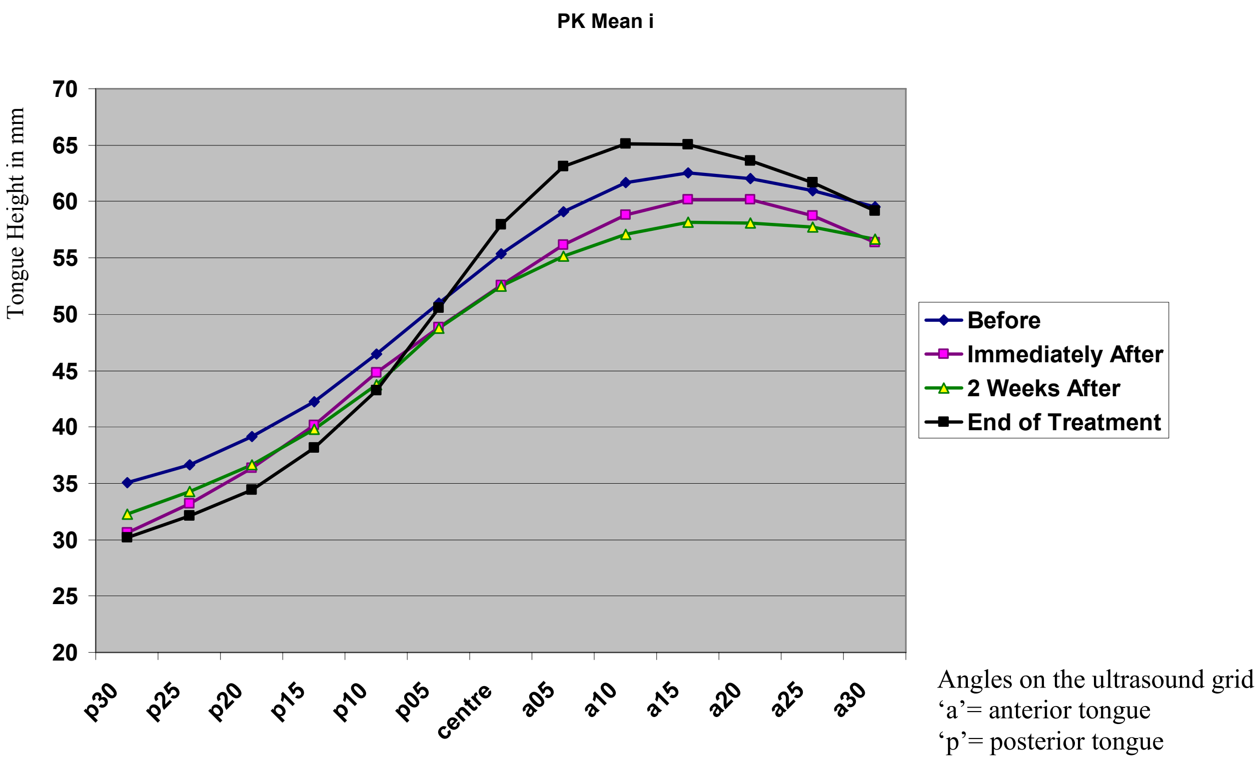


Figure 24. Mean tongue height for subject PK during /i/ vowel production at different examinations.

4.2.5.3. PK Tongue Height during /u/ Vowel Production

During /u/ vowel, no large differences were found in tongue height between different examinations except at the end of treatment examination, where the posterior part of the tongue (p30 to p15) was depressed and the anterior part of the tongue (centre to a20) was elevated (Tables 19, 20 ; Figure 25).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	35.1	37.3	40.2	43.7	47.5	50.9	54.0	55.9	57.1	57.4	56.8	56.1	55.6
Immediately After	32.7	36.5	41.0	45.6	49.8	52.2	53.5	54.1	54.3	54.6	54.8	54.4	53.9
2 Weeks After	34.7	37.4	40.2	43.5	47.0	49.7	51.7	52.8	53.8	54.3	54.3	53.7	52.3
End of Treatment	29.7	31.6	34.3	38.4	44.5	52.0	59.0	62.9	64.3	63.9	62.2	58.8	56.4

Table 19. Mean tongue height (mm) for subject PK during /u/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
2 weeks to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
End to Before	↓	↓	↓	↓	↔	↔	↑	↑↑	↑↑	↑	↑	↔	↔

Table 20. Relative increase or decrease in tongue height for subject PK during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

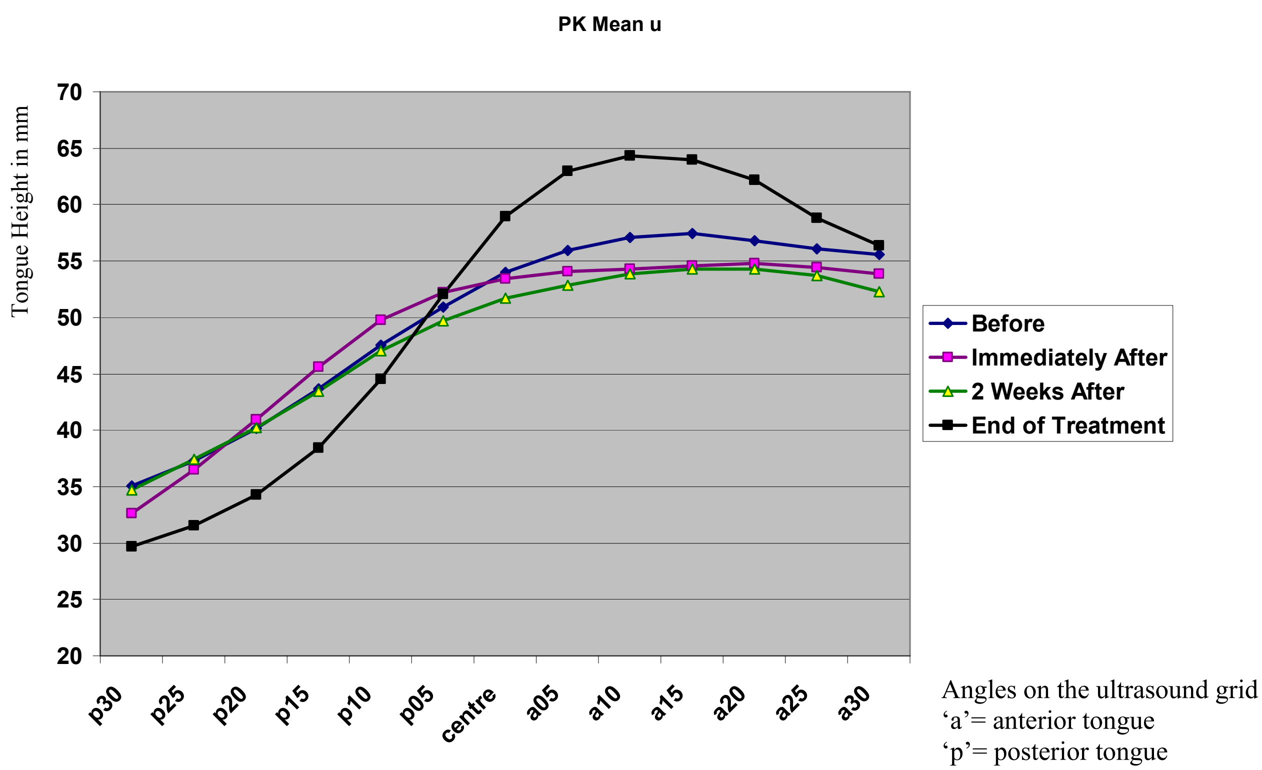


Figure 25. Mean tongue height for subject PK during /u/ vowel production at different examinations.

4.2.6. PK Tongue Rest Position Analysis

The tongue rest position for subject PK showed that there was no change in resting tongue position when examined immediately after BG appliance insertion and after 2 weeks. At the end of treatment the posterior part of the tongue (p40 to centre) was in a higher position compared to baseline (Tables 21, 22; Figure 26).

	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Before BG	40.5	42.2	44.2	46.3	48.6	50.7	52.5	54.2	55.5	56.4	56.5	56.7	56.4	56.4	56.7	57.1	57.3
Immedia-tely After	39.6	40.7	42.4	44.5	47.0	49.7	52.2	54.3	55.8	57.1	58.1	58.5	58.3	57.2	55.7	53.9	53.1
2 Weeks After	40.3	41.4	42.7	44.4	46.8	49.4	52.2	54.5	56.7	58.0	58.5	58.4	57.9	56.8	55.6	54.2	53.2
End of Treatment	46.3	47.7	49.6	51.5	53.8	56.6	58.7	60.1	60.0	59.2	58.4	57.6	57.3	57.2	57.2	57.1	57.3

Table 21. Mean tongue height (mm) at rest for subject PK. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
2 Weeks to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
End to Before	↑	↑	↑	↑	↑	↑	↑	↑	↑	↔	↔	↔	↔	↔	↔	↔	↔

Table 22. Relative increase or decrease in tongue height for subject PK at rest during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

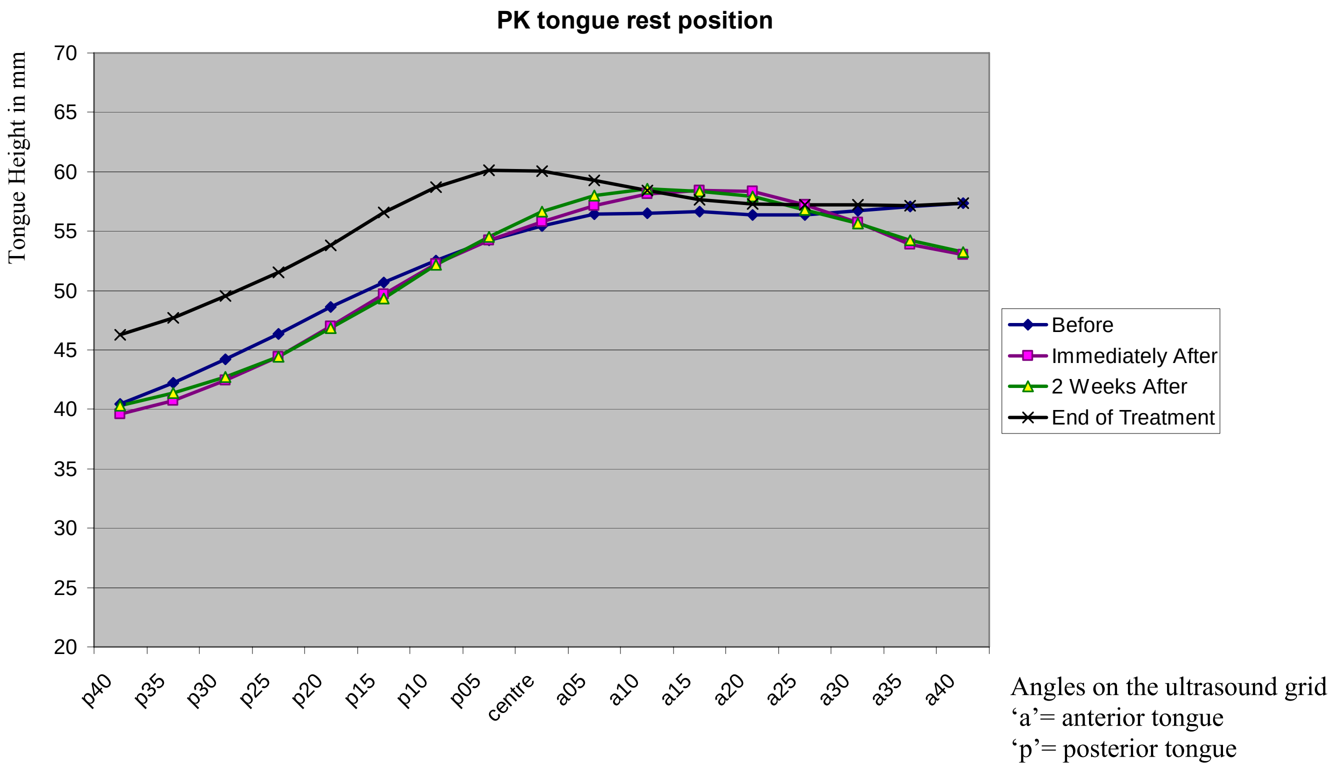


Figure 26. Mean tongue height at rest for subject PK during different examinations.

4.2.7. Speech Acceptability

The mean speech acceptability score for subject PK before BG appliance insertion was 0.52 ± 0.67, which increased to 1.98 ± 0.60 immediately after appliance insertion with a mean difference (Before – After) of -1.45 ± 0.92. This increase in acceptability score immediately after appliance insertion was significant compared to the baseline score (P < 0.001). After 2 weeks of treatment, the score was 1.76 ± 0.88 with a mean difference of -1.24 ± 0.98. This showed a significant increase compared to baseline score (P < 0.001). At the end of treatment, the score was 1.43 ± 0.80 with a mean difference of -0.90 ± 1.12, which showed a significant increase compared to baseline score (P < 0.001; Figure 27).

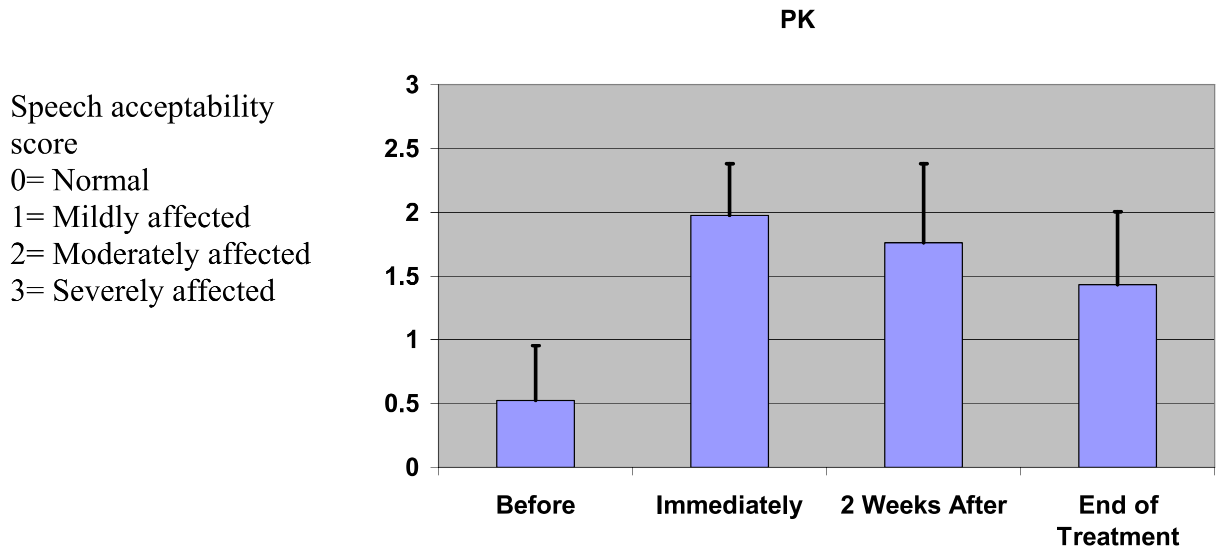


Figure 27. Mean speech acceptability scores for subject PK during different examinations.

4.3. Study Subject SE

Subject SE had a thumb-sucking habit. The BG appliance was inserted when she was 12 years and 1 month of age. The duration of treatment was 12 months and 17 days (382 days). The thumb-sucking habit was successfully eliminated. At the end of treatment ultrasound and voice records were obtained. Unfortunately, the sound on these files was found to be corrupted. The subject refused to duplicate new final records.

4.3.1. Cephalometry

The pre-treatment cephalometric analysis showed that subject SE had an SNA angle of 83.1° and an SNB angle of 77.3°. After removal of the BG appliance, the SNA angle increased to 84.5° while the SNB angle increased to 78.9°. The upper incisor to SN angle was 113.9° prior to treatment. In this respect there was slight change at the end of treatment. Lower incisor to MP was reduced from 103.2° to 99.4°. Consequently, the inter-incisal angle was increased from 103.6° to 107.9°. The pre-treatment LFH was 75.4 mm while after treatment it was 77.9 mm.

The upper lip to E line was reduced from 3.8 mm to 1.7 mm and the lower lip to E line decreased from 12.2 mm to 7.9 mm (Tables 23, 24).

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
SNA	83.1	84.5	81.2 ± 3.3
SNB	77.3	78.9	77.3 ± 2.7
ANB	5.8	5.6	3.9 ± 2.1
Upper 1 to SN	113.9	113.4	102.0 ± 2
Lower 1 to MP	103.2	99.4	91.4 ± 3.8
Inter-incisal angle	103.6	107.9	125.5 ± 9.7
Y Axis	64.6	64.7	59.4 ± 3.8

Table 23. Cephalometric angular measurements for subject SE.

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
MD Length	117.2	121.8	113.0 ± 4.9
Mx Unit Length	92.4	94.5	90.0 ± 3.7
Unit Difference	24.8	27.2	23.0
LFH	75.4	77.9	62 ± 4.6
Ulip to E line	3.8	1.7	0.0 ± 0.0
Lower Lip to E	12.2	7.9	-2.6 ± 2.0

Table 24. Cephalometric linear measurements (mm) for subject SE.

4.3.2. Study Models

The pre-treatment orthodontic models for subject SE showed that there was a 2 mm open bite between the maxillary and the mandibular incisors. At the end of the treatment the open bite was reduced to 0 mm. The total open bite reduction achieved was 2 mm. The initial overjet was 7 mm, which was reduced to 5 mm. SE had a super Class I molar relationship on the left side, which remained the same at the end of the treatment. The inter-molar cusp width measured 54 mm at both pre- and post-treatment (Table 25).

Measurement	Pre-treatment	Post-treatment
Overjet	7 mm	5 mm
Overbite	-2 mm (open bite)	0 mm
Inter-molar cusp width	54 mm	54 mm
Inter-molar width	36 mm	36 mm
Molar relationship	super Class I on left side, Class I on right side	super Class I on left side, Class I on right side

Table 25. Study model analysis for subject SE.

4.3.3. Clinical Photographs

The mean aesthetic score before treatment for subject SE was 3.32 ± 0.48. After treatment the mean score was reduced to 2.00 ± 0. There was a significant reduction in open bite score ($P < 0.001$) as indicated in the following clinical photographs.

SE Before Treatment

SE After Treatment

4.3.4. Tongue Ultrasound Analysis

4.3.5. SE Tongue Function Analysis

4.3.5.1. SE Tongue Height during /a/ Vowel Production

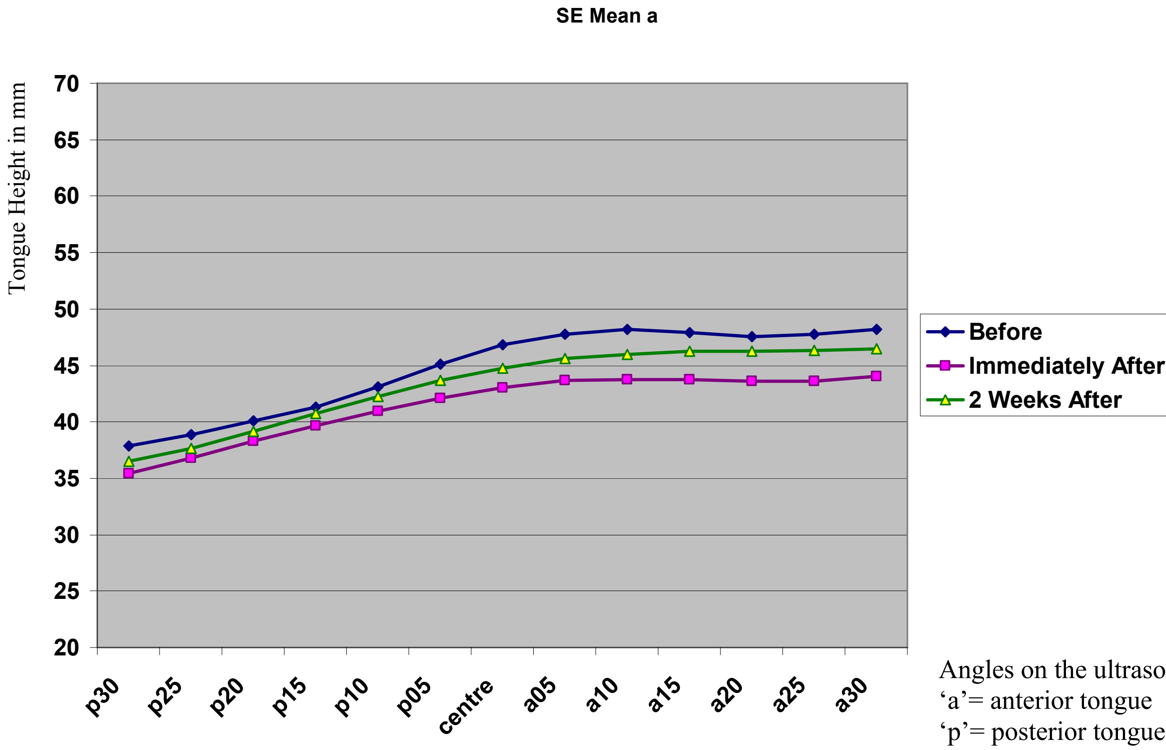
For subject SE, no large differences in tongue height were found immediately after and at 2 week examination during /a/ vowel production (Tables 26, 27; Figure 28). Unfortunately, we did not have information about the end of treatment examination because the voice on the ultrasound movies was corrupted.

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	37.8	38.9	40.1	41.3	43.1	45.1	46.8	47.8	48.2	47.9	47.6	47.8	48.2
Immediately After	35.4	36.8	38.3	39.6	40.9	42.1	43.0	43.6	43.8	43.7	43.6	43.6	44.0
2 Weeks after	36.5	37.7	39.1	40.7	42.3	43.7	44.7	45.6	46.0	46.3	46.3	46.3	46.4

Table 26. Mean tongue height (mm) for subject SE during /a/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
2 weeks to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 27. Relative increase or decrease in tongue height for subject SE during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.



Angles on the ultrasound grid
'a'= anterior tongue
'p'= posterior tongue

Figure 28. Mean tongue height for subject SE during /a/ vowel production at different examinations.

4.3.5.2. SE Tongue Height during /i/ Vowel Production

During /i/ vowel production, subject SE showed a depression of the anterior part of the tongue (a15 to a25) depressed when examined immediately after insertion. At the 2 week examination, the tongue height was close to the tongue height measured immediately after appliance insertion with the anterior part of the tongue (a05 to a25) depressed (Tables 28, 29; Figure 29). Unfortunately, we did not have information regarding the end of treatment examination since the voice on the ultrasound movies was corrupted.

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	30.4	31.1	32.3	34.4	37.4	41.3	46.3	52.8	58.6	62.4	64.1	64.3	60.1
Immediately After	28.0	29.6	31.8	34.5	38.2	42.4	46.6	50.6	54.7	57.5	59.3	59.5	58.7
2 Weeks after	28.4	30.0	32.4	34.9	38.3	41.1	44.6	48.0	52.1	55.5	57.8	58.1	57.2

Table 28. Mean tongue height (mm) for subject SE during /i/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↓	↓	↓	↔
2 weeks to Before	↔	↔	↔	↔	↔	↔	↔	↓	↓↓	↓↓	↓	↓	↔

Table 29. Relative increase or decrease in tongue height for subject SE during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

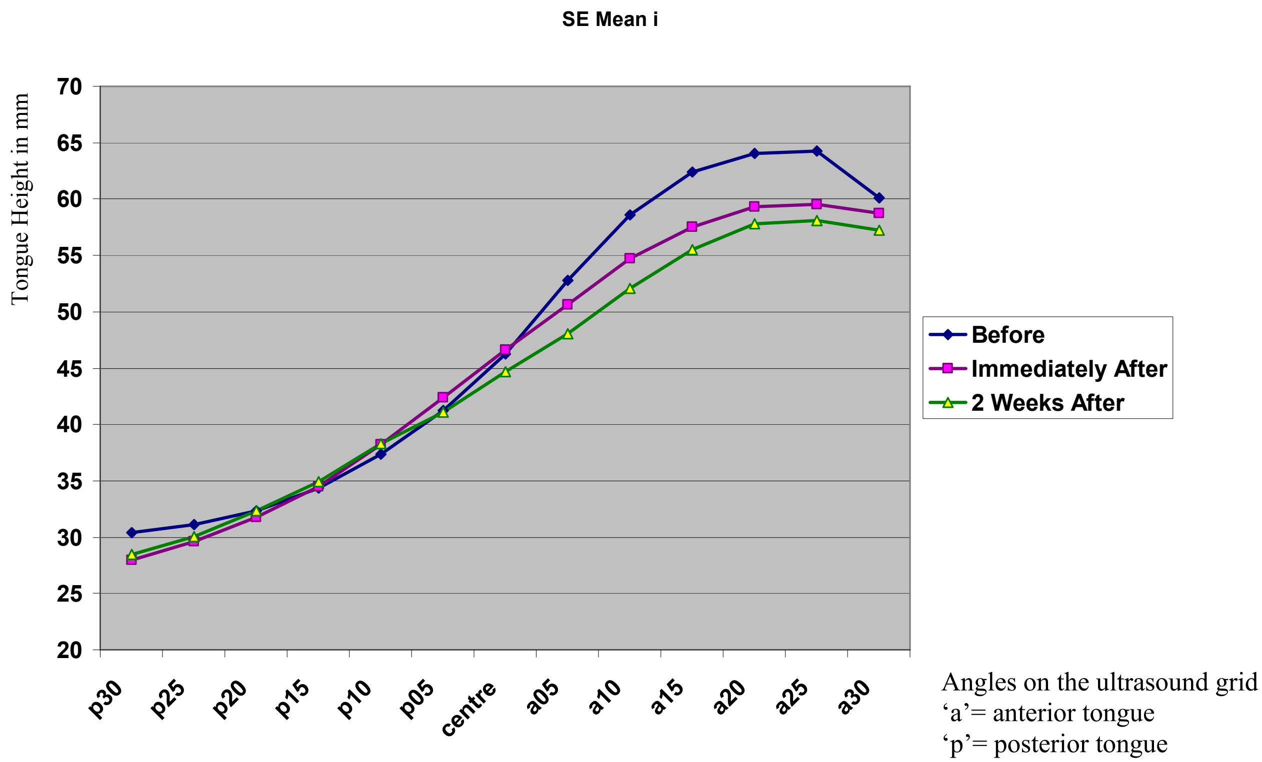


Figure 29. Mean tongue height for the subject SE during /i/ vowel production at different examinations.

4.3.5.3. SE Tongue Height during /u/ Vowel Production

During /u/ vowel production, the anterior part of the tongue (a10 to a30) at immediately after appliance insertion examination was lower in height compared to pre-treatment. Similarly, the anterior part of the tongue (a10 to a30) was depressed after 2 weeks (Tables 30, 31; Figure 30). Unfortunately, we did not have information regarding the end of treatment examination since the voice on the ultrasound movies was corrupted.

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	28.0	29.0	31.2	34.0	38.0	42.9	48.3	53.3	57.3	59.5	59.8	58.8	57.7
Immediately After	29.3	31.6	34.6	38.1	41.7	45.1	47.8	49.8	50.8	50.9	50.5	49.8	49.1
2 Weeks after	29.2	31.4	33.8	36.5	39.8	43.0	46.4	49.4	52.1	53.6	53.6	53.0	52.6

Table 30. Mean tongue height (mm) for subject SE during /u/ vowel production at different examinations. ‘a’ denotes ‘anterior tongue’ , ‘p’ denotes ‘posterior tongue’.

Post- Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↓	↓↓	↓↓	↓↓	↓↓
2 weeks to Before	↔	↔	↔	↔	↔	↔	↔	↔	↓	↓	↓	↓	↓

Table 31. Relative increase or decrease in tongue height for subject SE during different examinations. ‘a’ denotes ‘anterior tongue’ , ‘p’ denotes ‘posterior tongue’.

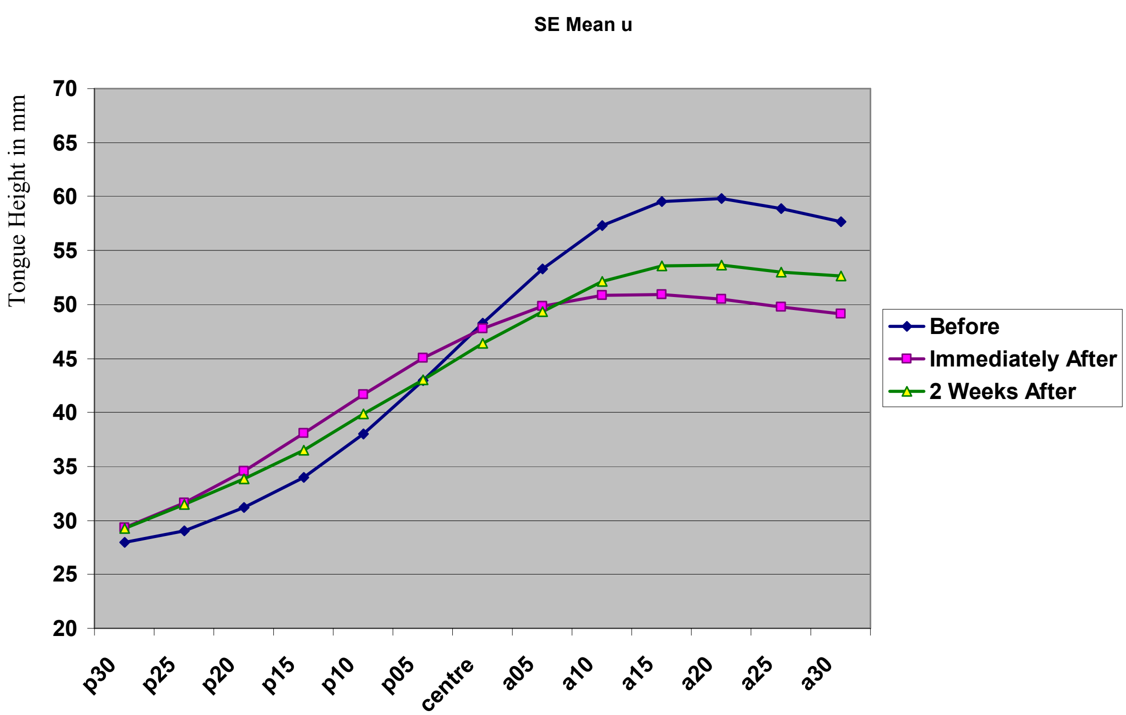


Figure 30. Mean tongue height for subject SE during /u/ vowel production at different examination.

4.3.6. SE Tongue Rest Position Analysis

For subject SE, the tongue height at rest was analyzed during different examinations. Upon examination, almost all parts of the tongue (p35 to a40) were depressed immediately after BG appliance insertion compared to pre-treatment. At 2 weeks and at the end of treatment the whole tongue was close to the baseline height (Tables 32, 33; Figure 31). Complete data regarding the tongue rest position for subject SE was obtained, although the voice was corrupted at the end of treatment examination. The end of treatment ultrasound recording was analysed without the need for the voice recording. As explained in the materials and methods section, the tongue rest position ultrasound frames were taken after each wet swallow when the tongue was still without any activity. For summary of tongue positions see the following tables and Figure (Tables 32, 33; Figure 31).

	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Before BG	39.7	41.1	42.9	44.8	47.0	49.3	51.5	54.0	56.5	58.6	60.3	60.4	60.1	59.6	58.6	57.4	58.3
Immedia-tely After	35.4	36.6	38.0	39.6	41.2	42.7	44.3	46.3	48.6	51.0	52.5	53.4	53.9	53.4	52.2	50.4	48.8
2 Weeks After	41.5	42.8	43.9	45.0	46.8	48.3	50.7	52.4	54.1	55.6	57.5	59.6	61.3	62.3	63.0	62.7	58.3
End of Treatment	39.7	41.2	43.1	45.1	46.8	48.6	50.2	52.1	53.2	54.4	55.7	56.5	56.7	56.6	55.9	54.9	54.8

Table 32. Mean tongue height (mm) at rest for subject SE. ‘a’ denotes ‘anterior tongue’, ‘p’ denotes ‘posterior tongue’.

Pre-post	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Immediate to Before	↔	↓	↓	↓	↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓	↓	↓	↓	↓↓	↓↓
2 weeks to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↑	↔
End to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↓	↔	↔	↔	↔	↔	↔

Table 33. Relative increase or decrease in the tongue height for subject SE at rest during different examinations. ‘a’ denotes ‘anterior tongue’ , ‘p’ denotes ‘posterior tongue’.

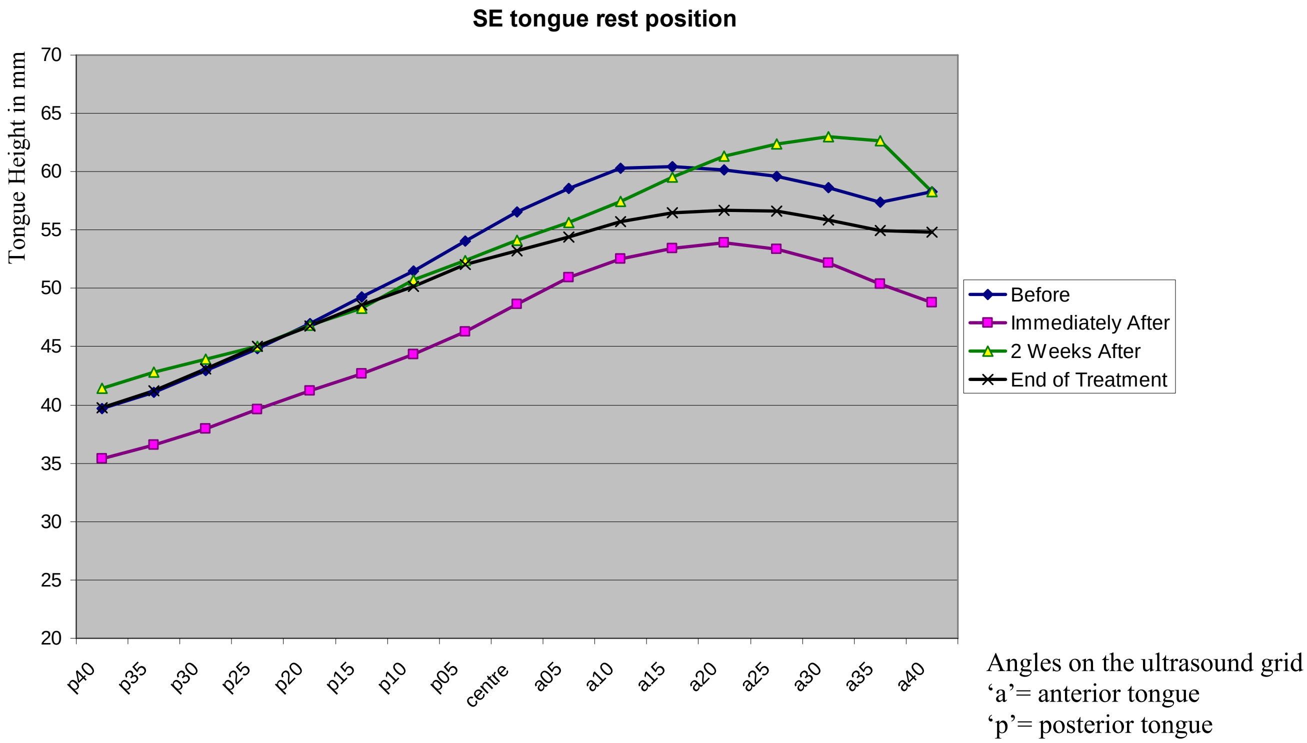


Figure 31. Mean tongue height at rest for subject SE during different examinations.

4.3.7. Speech Acceptability

The mean speech acceptability score for subject SE before BG appliance insertion was 0.83 ± 0.96, which increased to 2.52 ± 0.55 immediately after appliance insertion with a mean difference (Before – After) of -1.69 ± 1.14. This increase in acceptability score immediately after appliance insertion was significant compared to the baseline score ($P < 0.001$). After 2 weeks, the score was reduced to 0.69 ± 0.64 with a mean difference of 0.14 ± 0.84, this showed a non-significant change in the acceptability score compared to baseline score ($P = 0.24$; Figure 32). The end of treatment score was not calculated since the end of treatment recording was corrupted.

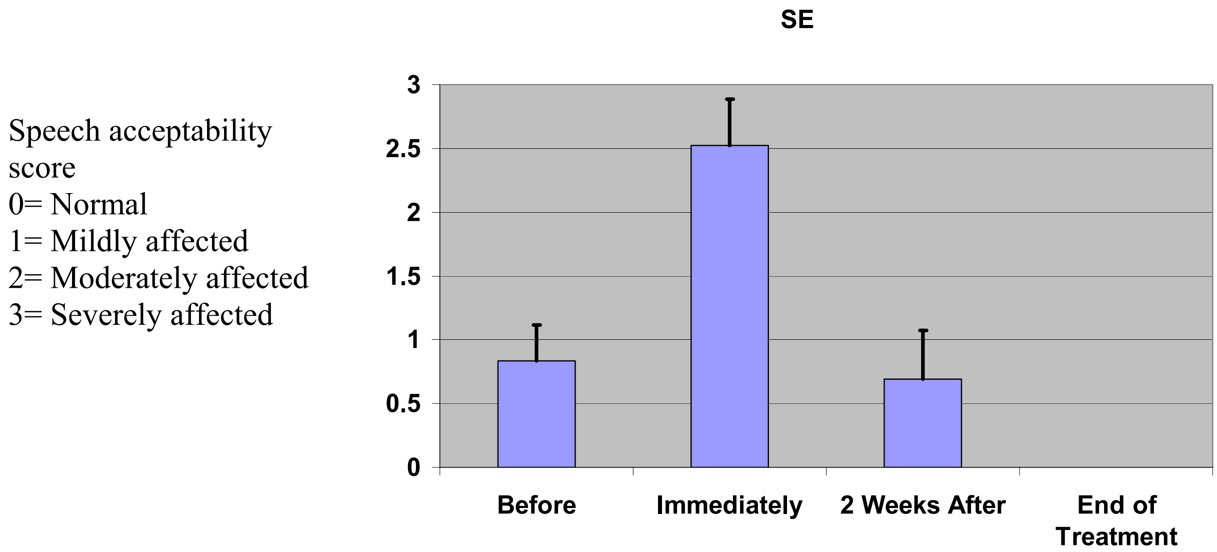


Figure 32. Speech acceptability scores for subject SE during different examinations.

4.4. Study Subject VP

Subject VP had a thumb-sucking habit. The BG appliance was inserted when she was 8 years and 9 months of age. The treatment duration was 10 months and 2 days (306 days). After insertion of the BG appliance, subject VP was happy to play with the roller instead of engaging in thumb-sucking. VP reported that she had a mild discomfort during eating at the first few days of appliance insertion. At the end of treatment, VP reported that she wanted the appliance to be removed. The thumb-sucking habit had successfully been eliminated.

4.4.1. Cephalometry

The pre-treatment cephalometric analysis showed that subject VP had an SNA angle of 83.0° and an SNB angle of 77.0°. After removal of the BG appliance the SNA angle increased to 84.0°, while the SNB angle increased to 78.0°. The upper incisor to SN angle increased from 114.8° to 123.6. Lower incisor to MP was reduced from 93.4° to 90.7°. The inter-incisal angle was reduced from 117.9° to 112.3°. The pre-treatment LFH was 66.4 mm while after treatment it was 67.4 mm. The upper lip to E line was -1.1 mm before treatment, which was decreased to -3.5 mm at the end of treatment. The lower lip to E line was reduced form 0.8 mm to -0.4. (Tables 34, 35).

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
SNA	83.0	84.0	81.4 ± 3.3
SNB	77.0	78.0	77.7 ± 2.7
ANB	6.0	6.0	3.7 ± 2.1
Upper 1 to SN	114.8	123.6	102.0 ± 2
Lower 1 to MP	93.4	90.7	91.4 ± 3.8
Inter-incisal Angle	117.9	112.3	125.5 ± 9.7
Y Axis	60.6	62.4	59.4 ± 3.8

Table 34. Cephalometric angular measurements for subject VP.

Measurement	Pre-treatment	Post-treatment	Standard for age± SD
MD Length	110.0	113.0	105.0 ± 4.4
Mx Unit Length	89.0	90.0	85.0 ± 3.4
Unit Difference	21.0	23.0	20.0
LFH	66.4	67.4	60 ± 4.3
Ulip to E line	-1.1	-3.5	0.0 ± 0.0
Lower Lip to E	0.8	-0.4	-2.0 ± 2.0

Table 35. Cephalometric linear measurements (mm) for subject VP.

4.4.2. Study Models

The pre-treatment orthodontic study models for subject VP showed that there was a 0 mm overbite relation between the maxillary and the mandibular incisors. At the end of the treatment a 2 mm positive over bite was achieved. The initial overjet of 9 mm increased to 10 mm at the end of treatment. VP had ½ cusp Class II molar relationship on the right side before starting treatment and at the end of treatment she had class I on both sides. Inter-molar cusp width increased from 49.5 mm to 51mm at the end of treatment (Table 36).

Measurement	Pre-treatment	Post-treatment
Overjet	9 mm	10 mm
Overbite	0 mm	+2 mm
Inter-molar cusp width	49.5 mm	51 mm
Inter-molar width	37.5 mm	38.5 mm
Molar relationship	½ cusp Class II on right, Class I on left	Class I both sides

Table 36. Study model analysis for subject VP.

4.4.3. Clinical Photographs

The mean aesthetic score before treatment for subject VP was 1.64 ± 0.58. After treatment, the mean score increased to 2.05 ± 0.79. There was a significant increase of open bite score (P = 0.007). See the following clinical photographs.

VP Before Treatment

VP After Treatment

4.4.4. Tongue Ultrasound Analysis

4.4.5. VP Tongue Function Analysis

4.4.5.1. VP Tongue Height during /a/ Vowel Production

The height of the tongue during /a/ vowel production for subject VP was close to baseline height during all different ultrasound examinations (Tables 37, 38; Figure 33).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	25.7	26.1	26.8	27.6	28.7	30.1	31.7	33.4	35.0	36.3	37.0	37.4	37.8
Immediately After	26.9	27.6	28.4	29.1	29.8	30.6	32.0	33.6	35.7	37.6	39.3	40.7	41.5
2 Weeks after	29.4	29.8	30.6	31.4	32.4	33.4	34.4	34.8	34.9	34.6	34.6	34.8	35.2
End of Treatment	28.2	29.2	30.3	31.4	32.6	33.6	34.5	35.3	35.8	36.0	36.0	36.1	36.3

Table 37. Mean tongue height (mm) for subject VP during /a/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Pre - post	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
2 weeks to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
End to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 38. Relative increase or decrease in tongue height for subject VP during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

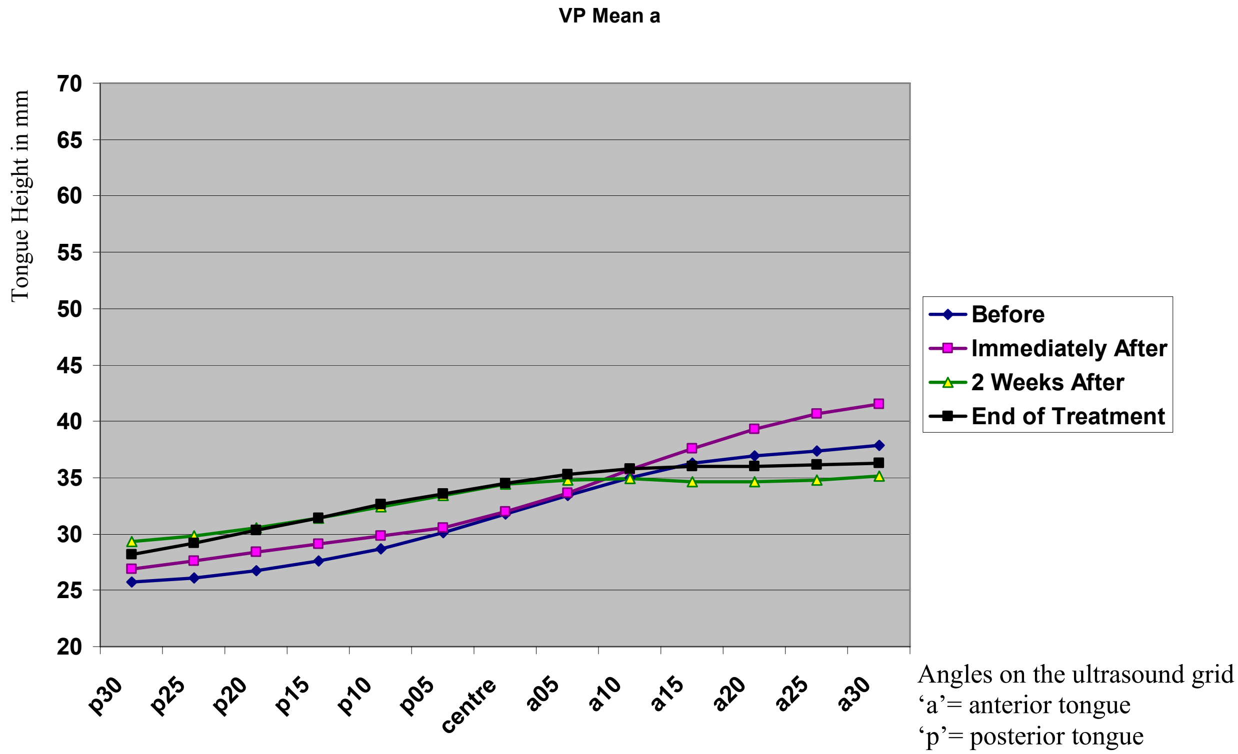


Figure 33. Mean tongue height for subject VP during /a/ vowel production at different examinations.

4.4.5.2. VP Tongue Height during /i/ Vowel Production

The only difference in tongue height noted for subject VP during /i/ vowel production was at 2 weeks after insertion where the posterior part of the tongue (p20 to centre) was elevated compared to baseline levels. At the end of treatment, the tongue height was close to the baseline height (Tables 39, 40; Figure 34).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	22.1	22.6	23.0	23.6	24.6	26.3	29.7	37.7	42.3	43.8	44.6	45.0	44.8
Immediately After	22.5	23.2	24.1	25.6	27.6	30.4	34.4	38.4	41.9	45.8	46.5	46.7	46.9
2 Weeks after	25.4	26.4	28.1	30.1	32.7	35.4	38.0	39.8	41.2	41.6	41.4	41.0	40.4
End of Treatment	23.2	23.8	24.7	25.8	27.5	30.1	33.3	37.3	41.7	44.2	45.9	46.4	46.4

Table 39. Mean tongue height (mm) for subject VP during /i/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↑	↔	↔	↔	↔	↔	↔
2 weeks to Before	↔	↔	↑	↑↑	↑↑	↑↑	↑↑	↔	↔	↔	↔	↔	↔
End to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 40. Relative increase or decrease in tongue height for subject VP during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

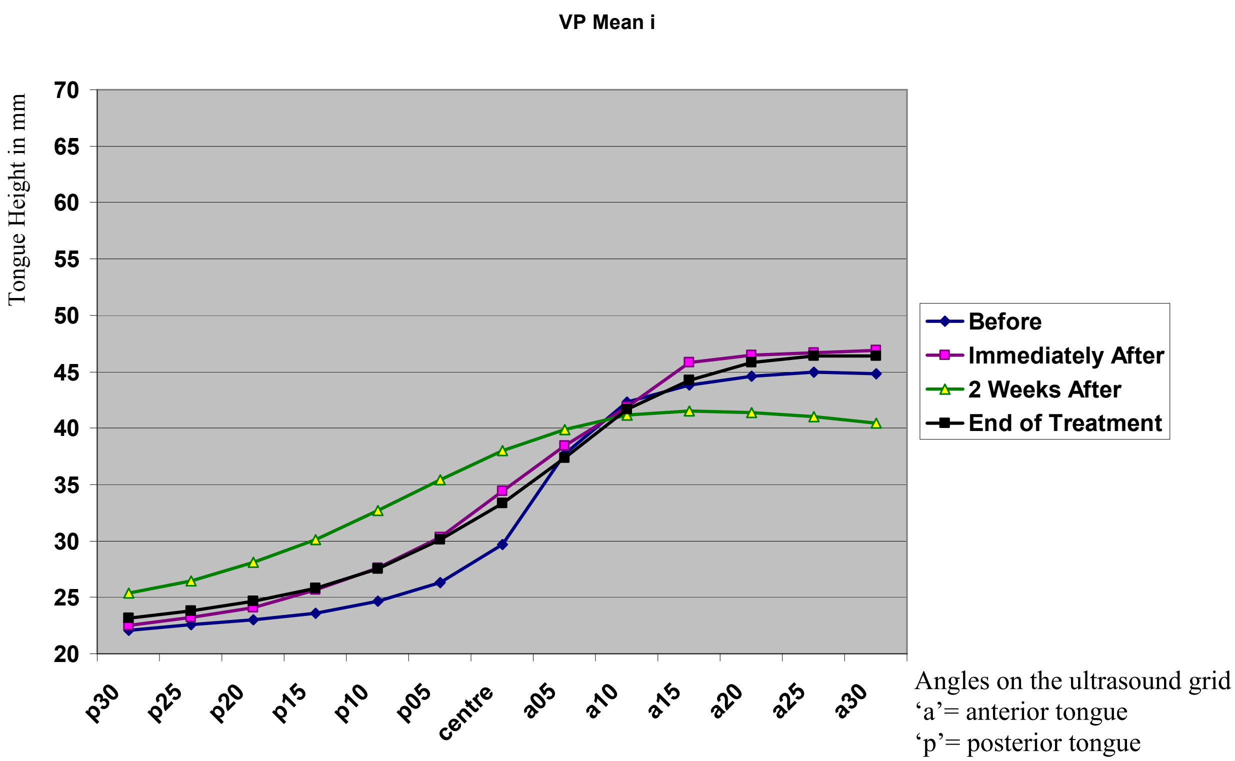


Figure 34. Mean tongue height for subject VP during /i/ vowel production at different examinations.

4.4.5.3. VP Tongue Height during /u/ Vowel Production

The tongue height during /u/ vowel production did not change a great deal. At the 2-week examination, the posterior part (p20 to p30) of the tongue was higher compared to baseline (Tables 41, 42; Figure 35).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before BG	24.4	25.6	27.1	28.9	31.1	33.6	35.8	37.3	38.2	38.3	37.9	37.9	37.9
Immediately After	25.8	26.8	28.4	30.3	32.3	34.8	37.1	39.3	40.7	41.6	42.2	42.9	43.5
2 Weeks after	29.3	30.6	32.0	33.2	34.6	35.7	36.6	37.3	37.5	37.2	36.7	36.1	35.4
End of Treatment	25.6	27.1	29.2	31.1	33.1	35.3	37.5	39.3	40.4	40.9	40.6	40.2	39.7

Table 41. Mean tongue height (mm) for subject VP during /u/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↑	↑
2 weeks to Before	↑	↑	↑	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
End to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 42. Relative increase or decrease in tongue height for subject VP during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

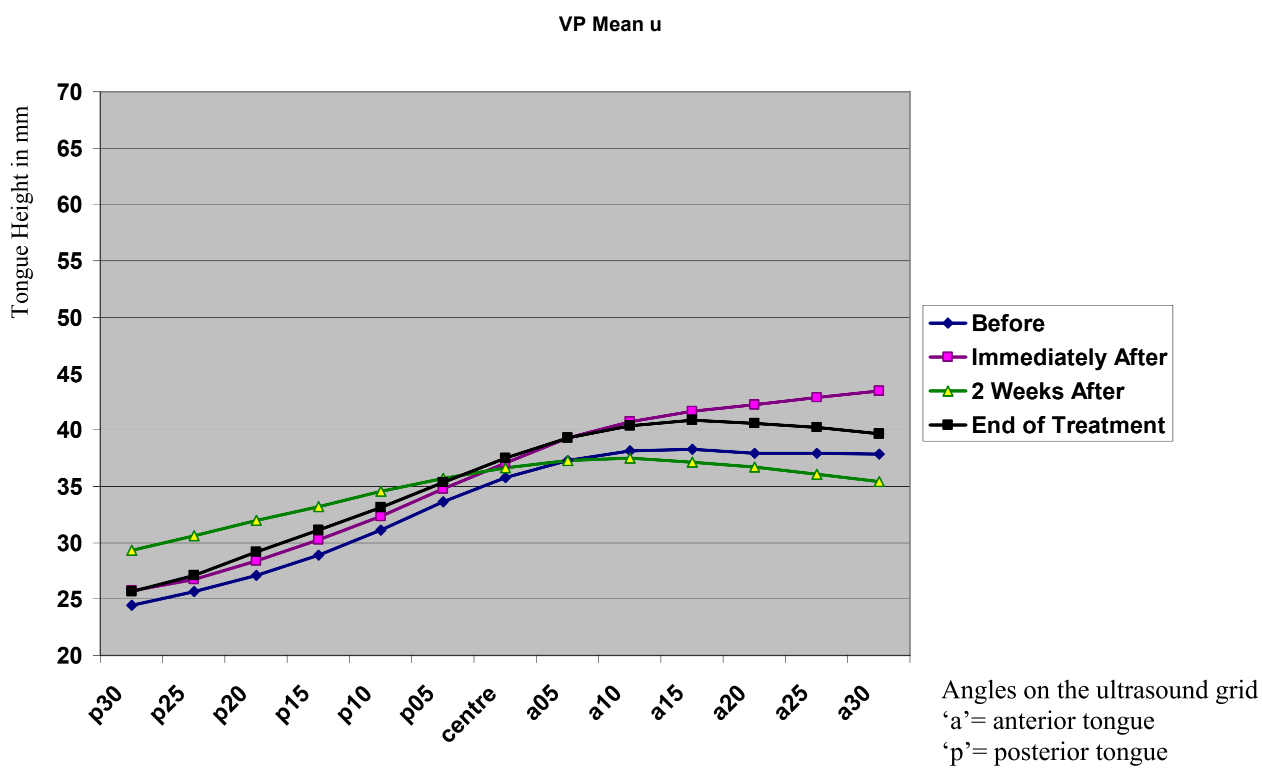


Figure 35. Mean tongue height for subject VP during /u/ vowel production at different examinations.

4.4.6. VP Tongue Rest Position Analysis

Examining the tongue at rest for subject VP indicated that there was no change in the height of the tongue immediately after appliance insertion. At 2 weeks post-insertion, the posterior part of the tongue (p35 to p15) was elevated. Similarly, the end of treatment examination showed that the posterior part of the tongue (p40 to p10) was elevated (Tables 43, 44; Figure 36).

	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Before BG	25.6	26.6	27.7	29.2	30.7	32.2	33.9	35.7	37.2	38.5	39.8	41.2	42.6	43.7	44.3	45.2	45.7
Immedia-tely After	29.0	29.8	30.8	32.3	33.5	35.5	37.4	39.4	41.0	42.1	42.9	43.7	43.7	43.7	43.8	43.9	42.3
2 Weeks After	30.0	31.1	32.5	34.0	35.2	37.0	38.0	38.9	39.5	40.0	40.3	40.6	41.0	41.2	41.4	41.1	40.8
End of Treatment	30.5	31.6	32.8	34.3	35.6	37.2	38.6	40.0	41.5	42.7	43.6	44.6	45.0	45.2	45.0	44.7	44.6

Table 43. Mean tongue height (mm) at rest for subject VP. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
2 weeks to Before	↔	↑	↑	↑	↔	↑	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↓
End to Before	↑	↑	↑	↑	↑	↑	↑	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 44. Relative increase or decrease in tongue height for subject VP at rest during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

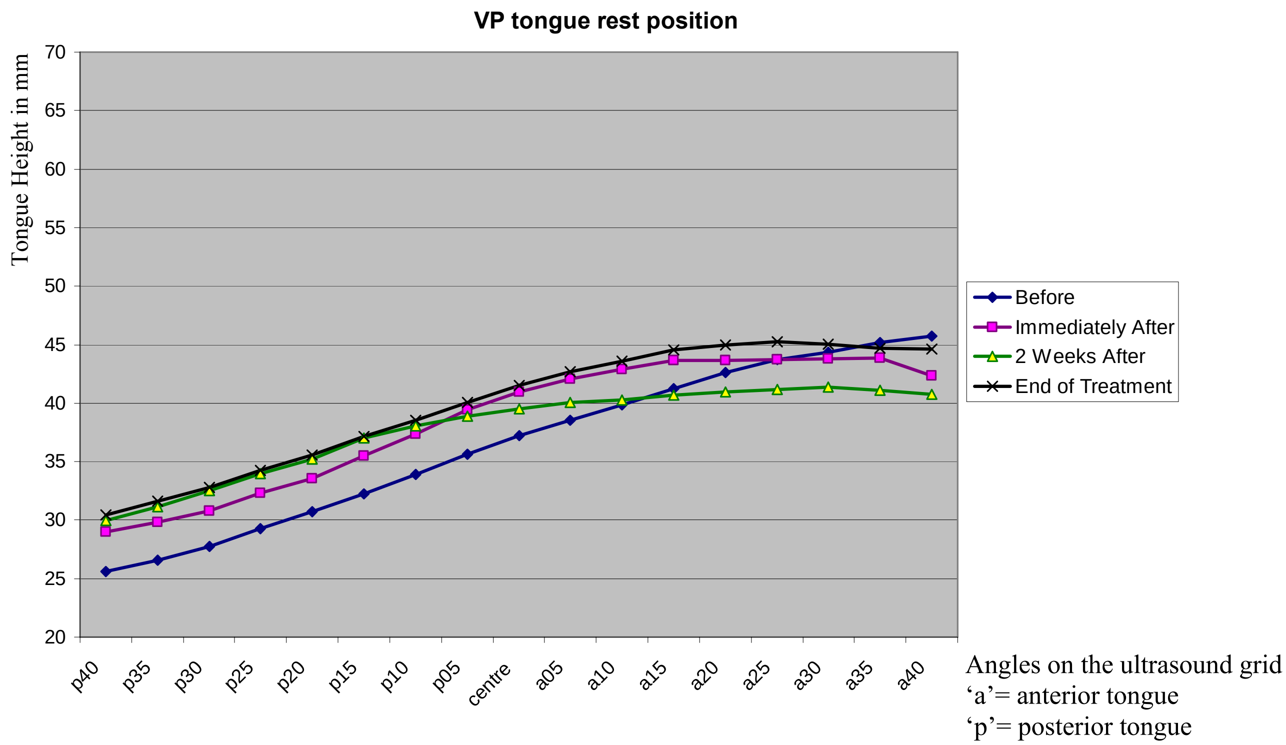


Figure 36 . Mean tongue height at rest for subject VP during different examinations.

4.4.7. Speech Acceptability

The mean speech acceptability score for subject VP before appliance insertion was 0.38 ± 0.58, which increased to 2.24 ± 0.66 immediately after insertion of the BG appliance with a mean difference (Before – After) of -1.86 ± 0.90. This increase in acceptability score immediately after appliance insertion was significant compared to the baseline score (P < 0.001). While after 2 weeks of appliance insertion the mean score was 1.38 ± 0.70 with a mean difference of -1.00 ± 0.86. This showed a significant increase compared to baseline score (P < 0.001). The end of treatment score increased to 1.60 ± 0.73 and a mean difference of -1.21 ± 1.00. This also showed a significant increase in score compared to baseline score (P < 0.001; Figure 37).

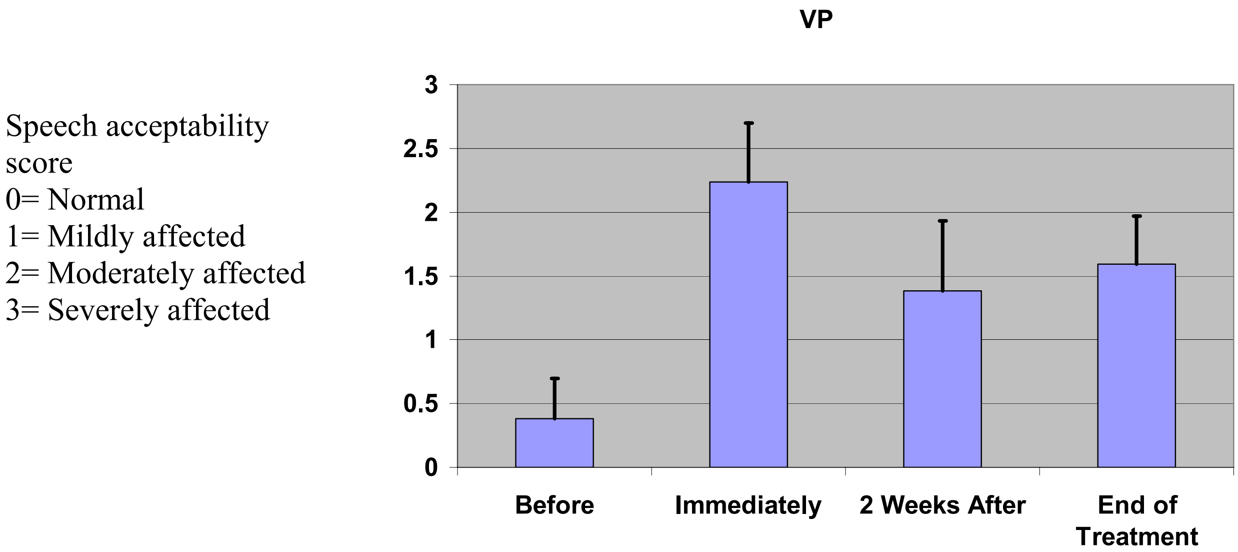


Figure 37. Mean speech acceptability scores for subject VP during different examinations.

4.5. Study Subject CE

Subject CE had a thumb-sucking habit. The MFT appliance was inserted when he was 12 years and 7 months of age. The treatment duration was 10 months and 12 days (316 days). Partial success was achieved as the subject stopped the habit but some compliance issues with wearing the MFT appliance had been reported. CE reported that the appliance kept falling from his mouth while he was sleeping. The treatment was stopped upon the parents request because the open bite was not eliminated.

4.5.1. Cephalometry

The pre-treatment cephalometric analysis showed that subject CE had an SNA angle of 81.8° and an SNB angle of 80.5°. After removal of the BG appliance, the SNA angle increased to 82.5° while the SNB angle did not change. The upper incisor to SN angle decreased from 114.9° to 113.4°. Lower incisor to MP was reduced from 92.7 ° to 89.4°. The inter-incisal angle increased from 114.4° to 118.2°. The pre-treatment LFH was 78.8 mm while after treatment it increased to 81.2 mm. There was minimal change in the upper lip to E line at the end of treatment, while the lower lip to E line reduced from 1.2 mm to -0.3 mm (Tables 45, 46).

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
SNA	81.8	82.5	81.2 ± 3.3
SNB	80.5	80.5	77.3 ± 2.7
ANB	1.3	2.0	3.9 ± 2.1
Upper 1 to SN	114.9	113.4	102.0 ± 2
Lower 1 to MP	92.7	89.4	91.4 ± 3.8
Inter-incisal angle	114.4	118.2	127.1 ± 9.7
Y Axis	64.0	58.7	59.4 ± 3.8

Table 45. Cephalometric angular measurements for subject CE.

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
MD Length	126.4	130.9	114.0 ± 4.9
Mx Unit Length	92.4	97.3	92.0 ± 3.7
Unit Difference	34.0	33.6	22.0
LFH	78.8	81.2	64.0 ± 4.6
Ulip to E line	-3.0	-2.9	0.0 ± 0.0
Lower Lip to E	1.2	-0.3	-2.6 ± 2.0

Table 46. Cephalometric linear measurements (mm) for subject CE.

4.5.2. Study Models

The pre-treatment orthodontic study models for subject CE showed that there was a 2.5 mm open bite between the maxillary and mandibular incisors. At the end of the treatment the open bite was measured at 2.0 mm resulting in a 0.5 mm open bite reduction. The initial overjet was 5 mm which was reduced to 4 mm at the end of treatment. The molar relationship (Class I) remained the same after treatment. Inter-molar cusp width remained the same at 51mm (Table 47).

Measurement	Pre-treatment	Post-treatment
Overjet	5 mm	4 mm
Overbite	-2.5 mm (open bite)	-2 mm (open bite)
Inter-molar cusp width	51 mm	51 mm
Inter-molar width	37 mm	37 mm
Molar relationship	Class I both sides	Class I both sides

Table 47. Study model analysis for subject CE.

4.5.3. Clinical Photographs

The mean aesthetic score before treatment for subject CE was 3.18 ± 0.50. After treatment, the mean score was reduced to 3.09 ± 0.53. There was a non-significant reduction of the open bite score (P = 0.41) as indicated in the following clinical photographs.

CE Before Treatment

CE After Treatment

4.5.4. Tongue Ultrasound Analysis

4.5.5. CE Tongue Function Analysis

4.5.5.1. CE Tongue Height during /a/ Vowel Production

No large differences were found at different examinations during /a/ vowel production for subject CE except for the most anterior part of the tongue, which was elevated at 2 weeks and at the end of treatment examinations (Tables 48, 49; Figure 38).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	44.8	45.2	45.4	45.3	44.9	44.4	43.9	43.2	42.7	42.3	41.8	41.7	41.9
2 Weeks After	40.6	41.9	42.7	43.4	43.5	43.6	43.7	44.0	44.6	45.5	46.3	47.5	49.2
End of Treatment	42.8	43.1	43.3	43.3	43.2	43.0	43.3	43.6	44.0	44.6	45.1	45.7	46.8

Table 48. Mean tongue height (mm) for subject CE during /a/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Pre - post	P30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
2 Weeks - Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↑	↑↑
End - Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↑

Table 49. Relative increase or decrease in tongue height for subject CE during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

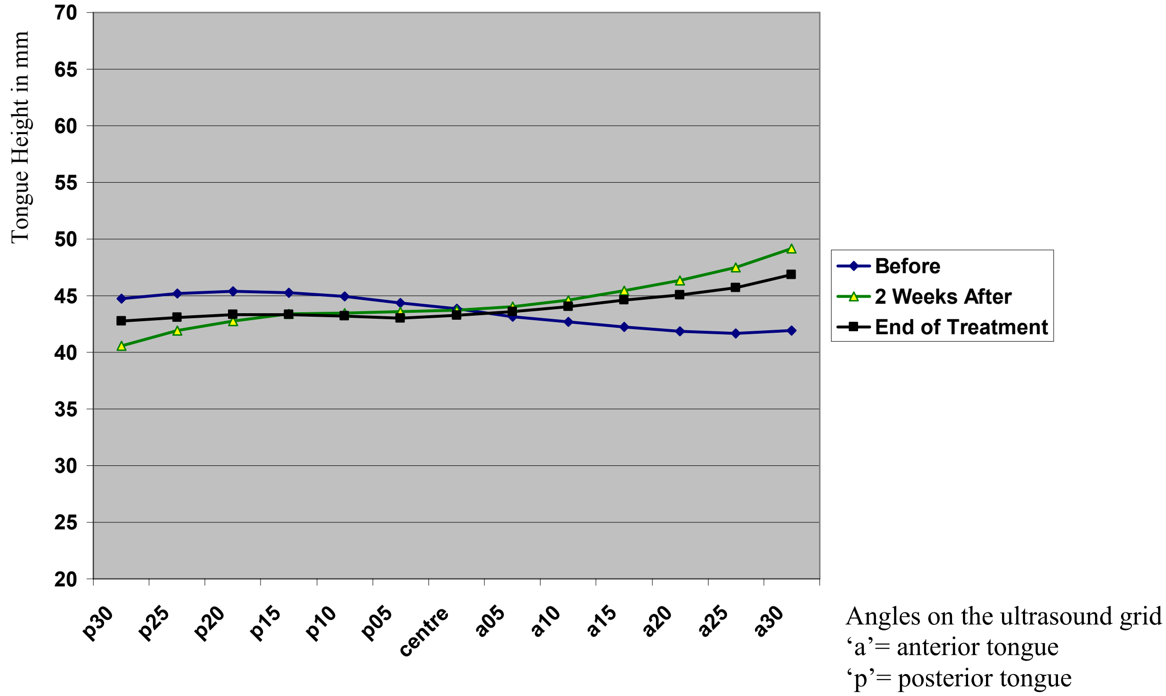


Figure 38. Mean tongue height for subject CE during /a/ vowel production at different examinations.

4.5.5.2. CE Tongue Height during /i/ Vowel Production

The examination of the tongue height during /i/ vowel at 2 weeks of appliance insertion revealed that the anterior part of the tongue (a15 to a30) was elevated while the posterior part (p30 to p10) was depressed. At the end of treatment, the tongue height was close to the baseline position (Tables 50, 51; Figure 39).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	34.1	36.5	39.8	43.6	46.2	48.1	49.0	49.5	49.8	49.8	49.9	50.1	50.4
2 Weeks After	28.5	30.3	32.7	35.3	39.1	43.6	47.2	50.4	52.7	54.4	55.3	55.7	55.9
End of Treatment	32.7	34.8	37.5	40.6	43.7	46.6	49.2	50.9	52.1	52.5	52.6	52.4	52.5

Table 50. Mean tongue height (mm) for subject CE during /i/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Pre - post	P30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
2 Weeks - Before	↓	↓	↓↓	↓↓	↓↓	↔	↔	↔	↔	↑	↑	↑	↑
End - Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 51. Relative increase or decrease in tongue height for subject CE during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

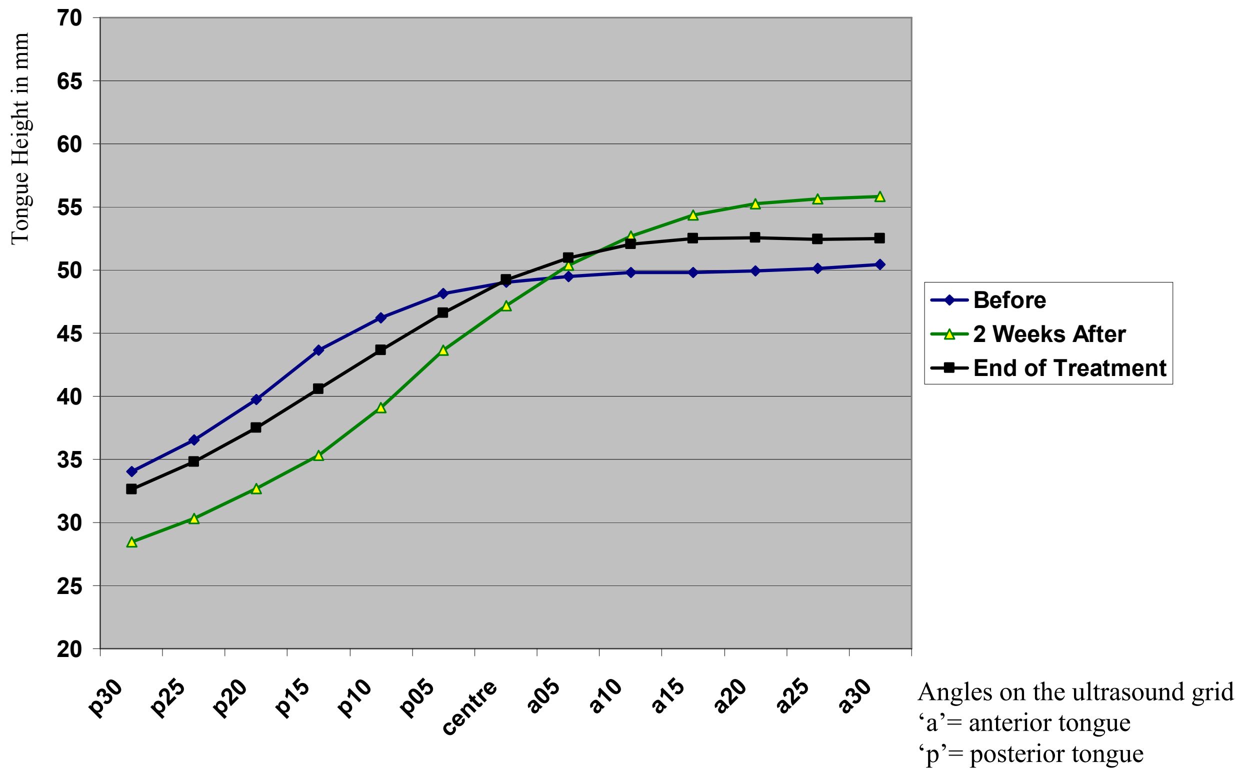


Figure 39. Mean tongue height for subject CE during /i/ vowel production at different examinations.

4.5.5.3. CE Tongue Height during /u/ Vowel Production

During /u/ vowel production, the tongue showed the same trend as in /i/ vowel production. After weeks, the anterior part of the tongue (a20 to a30) was elevated while the posterior part (p30 to p10) was depressed. At the end of treatment, only the anterior part of the tongue (a25 to a30) was elevated (Tables 52, 53; Figure 40).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	36.1	39.3	43.1	46.6	49.1	50.5	51.0	50.8	50.1	49.4	48.3	47.6	47.0
2 Weeks After	31.0	34.0	37.3	40.8	44.0	46.6	49.3	51.2	52.5	53.1	53.5	53.6	53.7
End of Treatment	37.0	40.0	43.1	45.9	48.0	49.6	50.7	51.3	51.8	51.9	51.9	52.2	52.5

Table 52. Mean tongue height (mm) for subject CE during /u/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Pre - post	P30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
2 Weeks to Before	↓	↓	↓	↓	↓	↔	↔	↔	↔	↔	↑	↑	↑↑
End to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↑	↑

Table 53. Relative increase or decrease in tongue height for subject CE during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

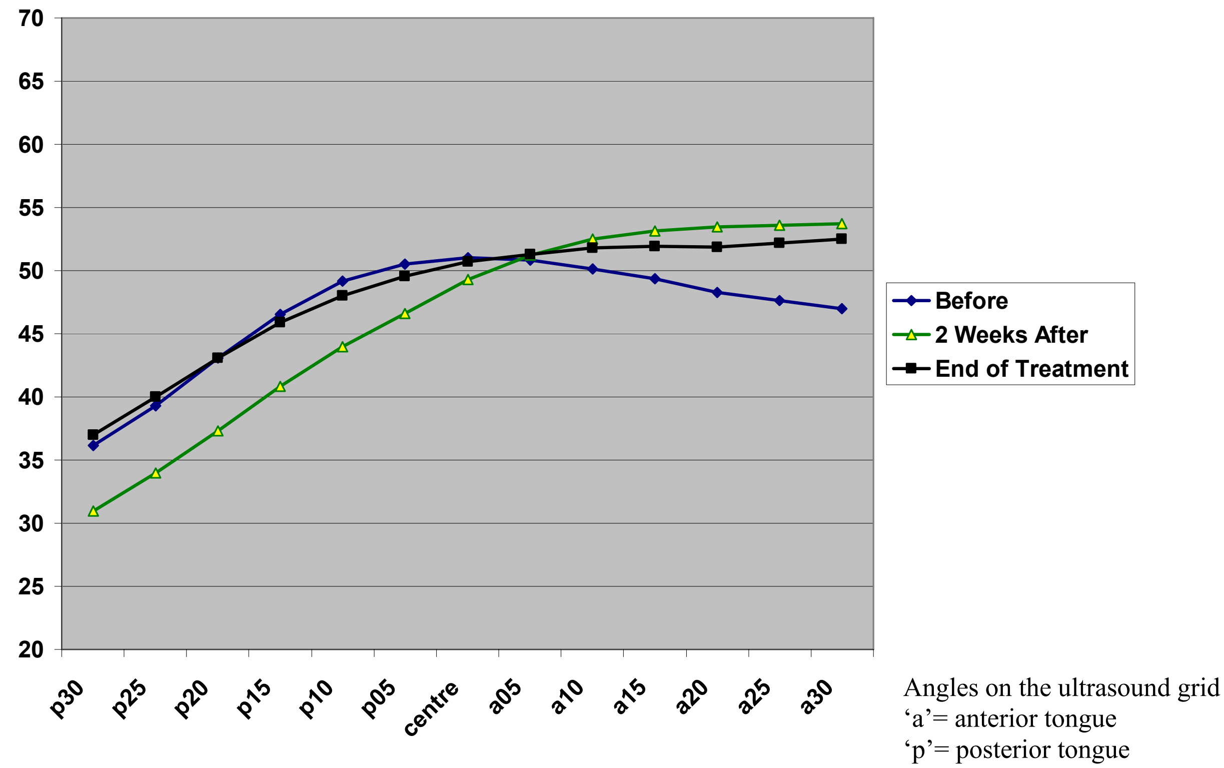


Figure 40. Mean tongue height for subject CE during /u/ vowel production at different examinations.

4.5.6. CE Tongue Rest Position Analysis

Examining the tongue height at rest showed that after 2 weeks of appliance insertion the anterior part of the tongue (a15 to a40) was higher while the posterior part (p40 to p15) was lower in position compared to baseline. At the end of treatment, only the anterior part of the tongue (a25 to a35) was higher in position (Tables 54, 55; Figure 41).

	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Before MFT	43.2	44.0	44.9	45.8	46.7	47.9	48.8	49.8	50.8	51.3	51.4	51.2	50.8	50.1	49.5	49.6	50.1
2 weeks After	35.7	36.8	38.0	39.5	41.2	43.0	45.3	47.8	50.4	52.8	54.9	56.3	57.3	58.1	58.7	60.1	61.7
End	41.9	43.1	44.0	45.1	45.9	47.2	48.7	50.1	51.7	53.0	54.3	54.9	55.0	54.7	54.2	54.1	54.1

Table 54. Mean tongue height (mm) at rest for subject CE. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Pre -post	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
2 weeks to Before	↓↓	↓↓	↓↓	↓	↓	↓	↔	↔	↔	↔	↔	↑	↑↑	↑↑	↑↑	↑↑	↑↑
End to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↑	↑	↑	↔

Table 55. Relative increase or decrease in tongue height for subject CE at rest during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

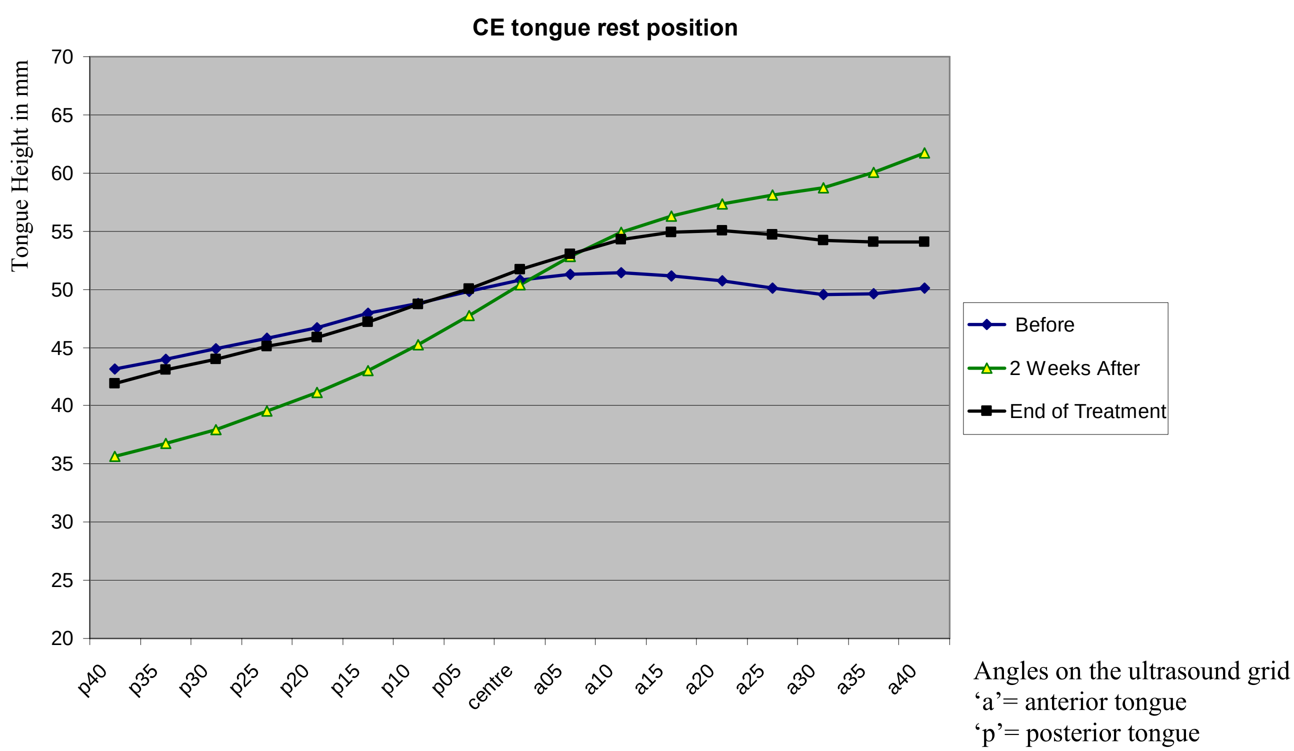


Figure 41. Mean tongue height at rest for subject CE during different examinations.

4.5.7. Speech Acceptability

The mean speech acceptability score for subject CE was 0.88 ± 0.99 before appliance insertion. After 2 weeks the score was 1.02 ± 0.64 with a mean difference (Before – After) of -0.14 ± 1.12. This showed a non-significant change from the baseline score (P = 0.38). At the end of treatment the score was 0.52 ± 0.67 with a mean difference of 0.36 ± 1.19. This showed a non-significant change from the baseline score (P = 0.06; Figure 42). No recording was performed immediately after appliance insertion examination in the MFT group as the subjects were not expected to talk with removable functional appliances in place.

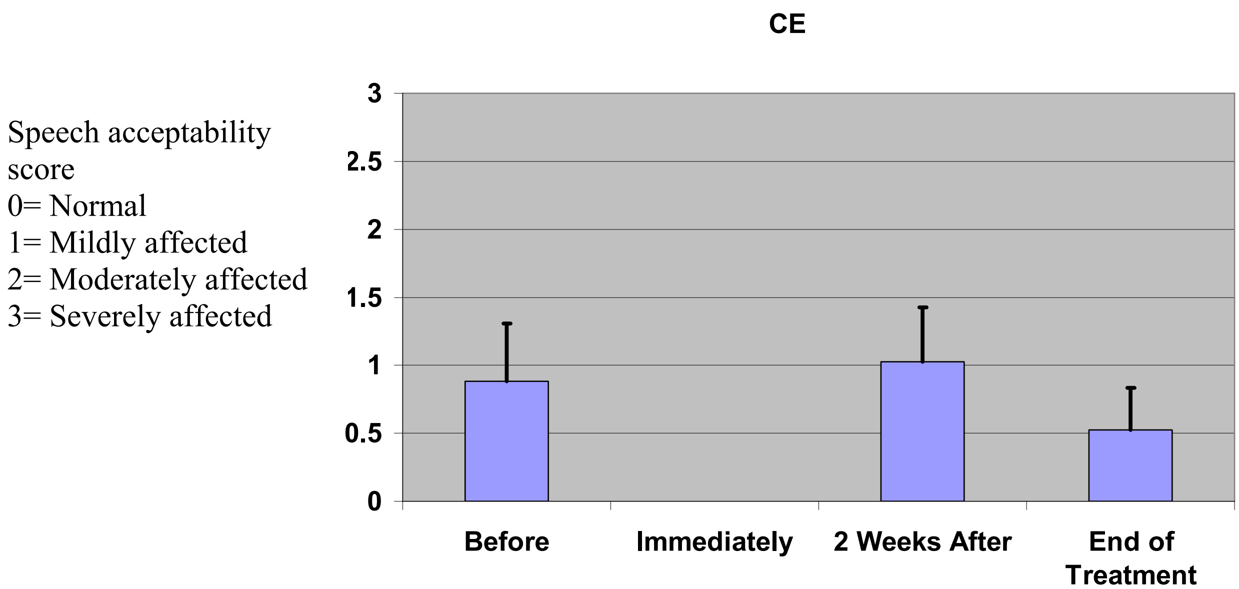


Figure 42. Mean speech acceptability scores for subject CE during different examinations.

4.6. Study Subject OS

Subject OS had a thumb-sucking habit. The MFT appliance was inserted when the subject was 12 years and 1 month of age. The treatment duration was 12 months and 21 days (386 days).

There was a partial success of the habit-breaking as OS reported that she would occasionally indulge in the habit.

4.6.1. Cephalometry

The pre-treatment cephalometric analysis showed that subject OS had an SNA angle of 92.0° and an SNB angle of 85.0°. After removal of the BG appliance, the SNA angle decreased to 91.0° while the SNB remained the same. The upper incisor to SN angle was 114° that increased to 116.0° at the end of treatment. Lower incisor to MP decreased from 121.7° to 114.2°. The inter-incisal angle increased from 107.4° to 115.6°. The pre-treatment LFH was 60.5 mm while after treatment LFH was 61.6 mm. The upper lip to E line decreased from 1.8 mm to 0.5 mm and the lower lip to E line decreased from 1.7 mm to 0.9 mm at the end of treatment (Tables 56, 57).

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
SNA	92.0	91.0	81.4 ± 3.3
SNB	85	85.0	77.7 ± 2.7
ANB	7.0	6.0	3.7 ± 2.1
Upper 1 to SN	114.0	116.0	102.0 ± 2.0
Lower 1 to MP	121.7	114.2	91.4 ± 3.8
Inter-incisal Angle	107.4	115.6	125.5 ± 9.7
Y Axis	55.0	53.0	59.4 ± 3.8

Table 56. Cephalometric angular measurements for subject OS.

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
MD Length	111.0	117.0	113.0 ± 4.9
Mx Unit Length	95.5	97.0	90.0 ± 3.7
Unit Difference	15.9	20.5	23.0
LFH	60.5	61.6	62.0 ± 4.6
Ulip to E line	1.8	0.5	0.0 ± 0.0
Lower Lip to E	1.7	0.9	-2.8 ± 2.0

Table 57. Cephalometric linear measurements (mm) for subject OS.

4.6.2. Study Models

The pre-treatment orthodontic study models for subject OS showed that there was a 0.5 mm positive overbite between the maxillary and the mandibular incisors. At the end of the treatment, a 2.5 mm positive over bite was achieved. The overjet which was initially 6.5 mm was reduced to 5.5 mm at the end of treatment. OS had ½ cusp Class II molar relationship on both sides before treatment whereas after treatment she had ½ cusp Class II on the right side. Inter- molar cusp width remained the same at 52 mm (Table 58).

Measurement	Pre-treatment	Post-treatment
Overjet	6.5 mm	5.5 mm
Overbite	+0.5 mm	+2.5 mm
Inter-molar cusp width	52 mm	52 mm
Inter-molar width	35 mm	35.5 mm
Molar relationship	½ cusp Class II both sides	½ cusp Class II right side

Table 58. Study model analysis for subject OS.

4.6.3. Clinical Photographs

The mean aesthetic score before treatment for subject OS was 1.23 ± 0.43. After treatment, the mean score was reduced to 1.00 ± 0. The P-value was 0.025. See the following clinical photographs.



OS Before Treatment

OS After Treatment

4.6.4. Tongue Ultrasound Analysis

4.6.5. OS Tongue Function Analysis

The subject OS received an extra ultrasound examination in comparison to other subjects in the MFT group. OS was examined immediately after appliance insertion and the ultrasound recording performed with the MFT appliance to test for different changes while the subject spoke with the appliance in place. The other subjects in the MFT group were not examined immediately after appliance insertion.

4.6.5.1. OS Tongue Height during /a/ Vowel Production

No changes could be noted with respect to the tongue height for subject OS during /a/ vowel production at different examinations (Tables 59, 60; Figure 43).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	30.4	32.0	33.7	35.0	36.0	37.1	38.2	39.2	40.1	41.1	41.9	43.1	44.4
Immediately After	33.3	34.7	36.2	37.4	38.5	39.5	40.4	41.3	42.2	42.6	42.7	42.1	41.6
2 Weeks After	29.7	31.0	32.3	33.9	35.3	36.7	37.9	38.6	38.9	39.1	39.4	39.7	40.5
End of Treatment	30.2	32.0	34.2	35.9	38.3	40.0	41.2	42.0	42.6	42.8	43.3	44.1	45.9

Table 59. Mean tongue height (mm) for subject OS during /a/ vowel production at different examinations. ‘a’ denotes ‘anterior tongue’ , ‘p’ denotes ‘posterior tongue’.

Pre - post	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
2 weeks to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
End to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 60. Relative increase or decrease in tongue height for subject OS during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

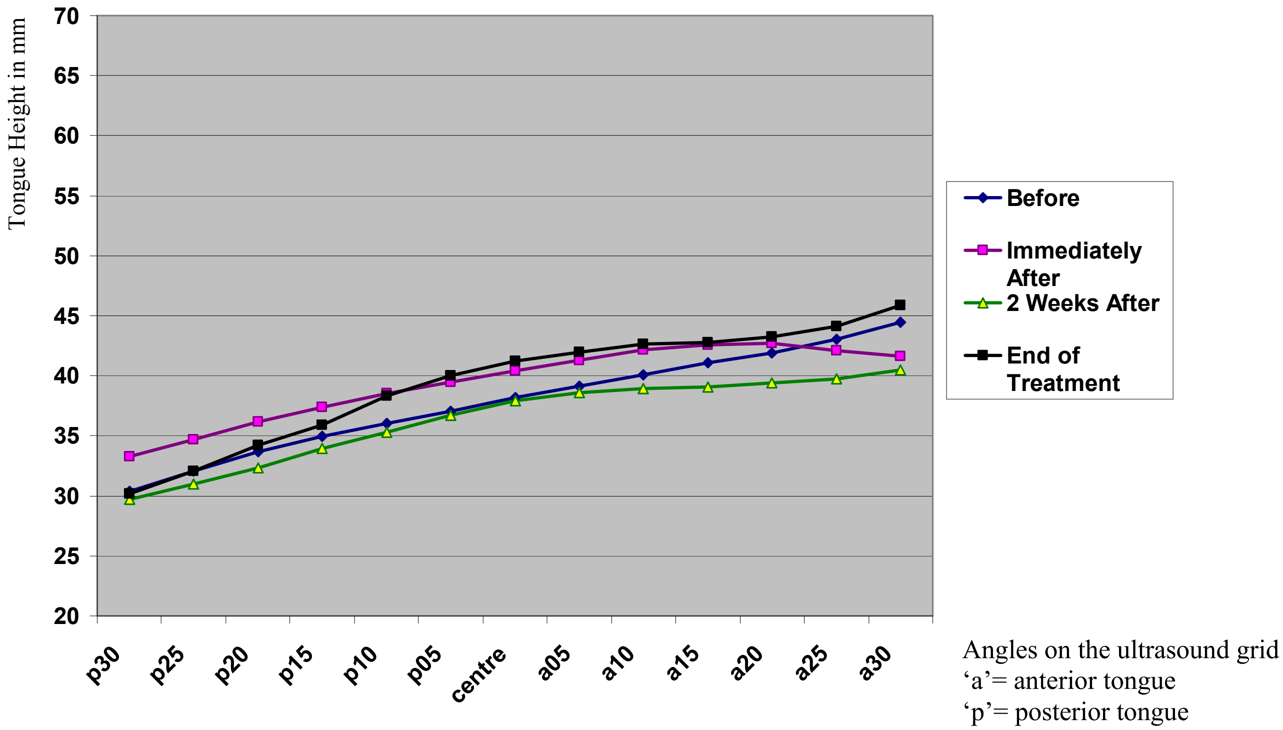


Figure 43. Mean tongue height for subject OS during /a/ vowel production at different examinations.

4.6.5.2. OS Tongue Height during /i/ Vowel Production

For OS, the tongue height during /i/ vowel production was close to the height when it was examined immediately after appliance insertion. In comparing the 2-week and end of treatment examinations, the posterior and the centre parts of the tongue (p30 to centre) were lower in height compared to baseline (Tables 61, 62; Figure 44).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	24.4	26.7	29.7	33.3	37.3	40.7	43.6	46.5	48.7	50.8	52.2	53.2	53.7
Immediately After	26.5	28.0	29.8	32.1	34.5	37.9	41.2	44.4	47.0	48.8	49.6	49.8	49.5
2 weeks After	20.4	21.7	23.5	25.9	29.5	33.6	38.0	42.8	46.5	49.1	50.4	50.7	50.6
End of Treatment	18.7	19.9	21.1	23.2	27.6	35.2	44.1	49.6	52.9	54.8	55.3	54.7	54.0

Table 61. Mean tongue height (mm) for subject OS during /i/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Pre - post	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
2 weeks to Before	↔	↓	↓	↓↓	↓↓	↓↓	↓	↔	↔	↔	↔	↔	↔
End to Before	↓	↓↓	↓↓	↓↓	↓↓	↓	↔	↔	↔	↔	↔	↔	↔

Table 62. Relative increase or decrease in tongue height for subject OS during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

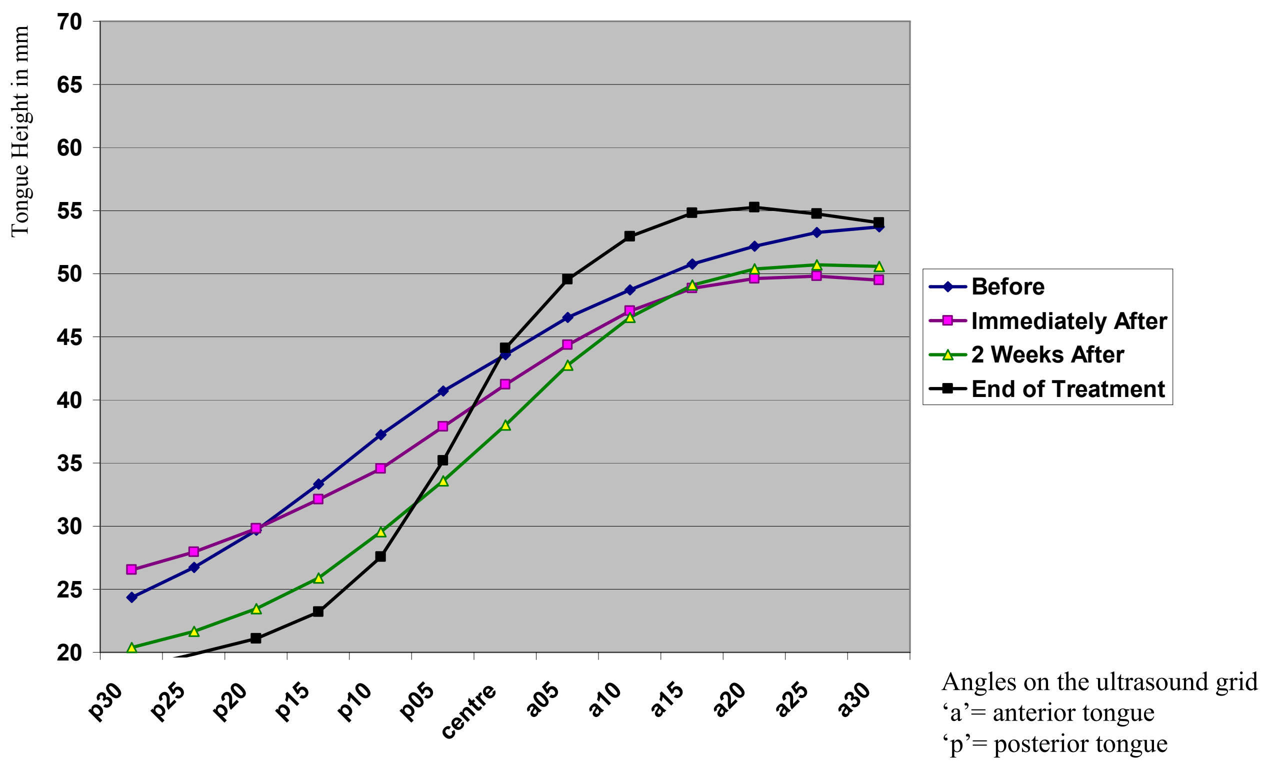


Figure 44. Mean tongue height for subject OS during /i/ vowel production at different examinations.

4.6.5.3. OS Tongue Height during /u/ Vowel Production

During /u/ vowel production, the tongue height immediately after appliance examination was close to baseline except for the anterior part (a25 to a30) that was depressed. At the 2-week examination, the tongue was almost in the same position as immediately after examination. No changes in tongue height were observed at the end of treatment compared to baseline (Tables 63, 64; Figure 45).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	24.1	26.4	29.5	33.3	36.8	40.0	42.7	44.8	46.8	48.4	49.9	51.2	52.3
Immediately After	28.1	30.6	33.2	35.9	38.5	40.8	42.8	44.5	45.9	46.6	46.8	46.1	44.7
2 Weeks after	21.5	23.7	27.3	31.6	35.9	38.9	41.9	44.0	44.8	45.0	45.1	45.1	45.2
End of Treatment	21.2	24.1	27.9	32.9	37.3	40.9	43.7	45.9	47.5	48.2	48.5	48.6	48.8

Table 63. Mean tongue height (mm) for subject OS during /u/ vowel production at different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Post - Pre	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Immediate-Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↓	↓↓
2 weeks - Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↓	↓	↓↓
End - Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 64. Relative increase or decrease in the tongue height during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

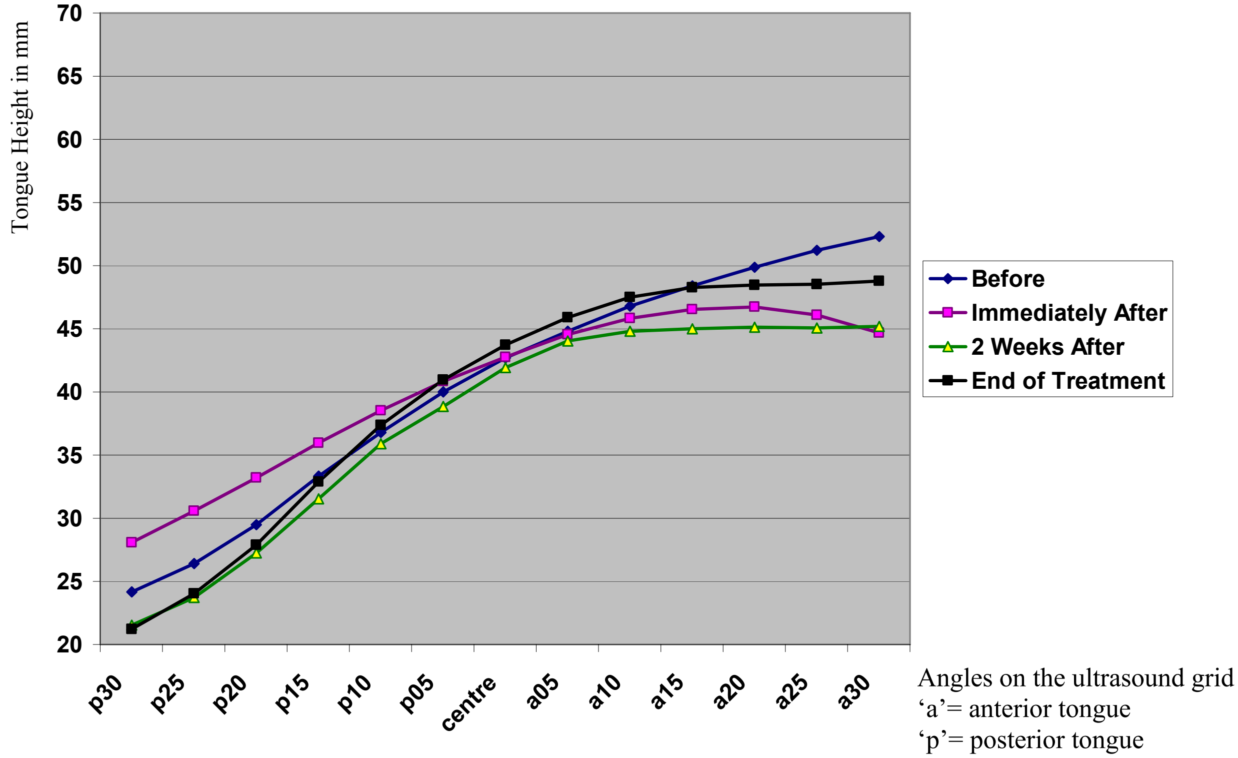


Figure 45. Mean tongue height for subject OS during /u/ vowel production at different examinations.

4.6.6. OS Tongue Rest Position Analysis

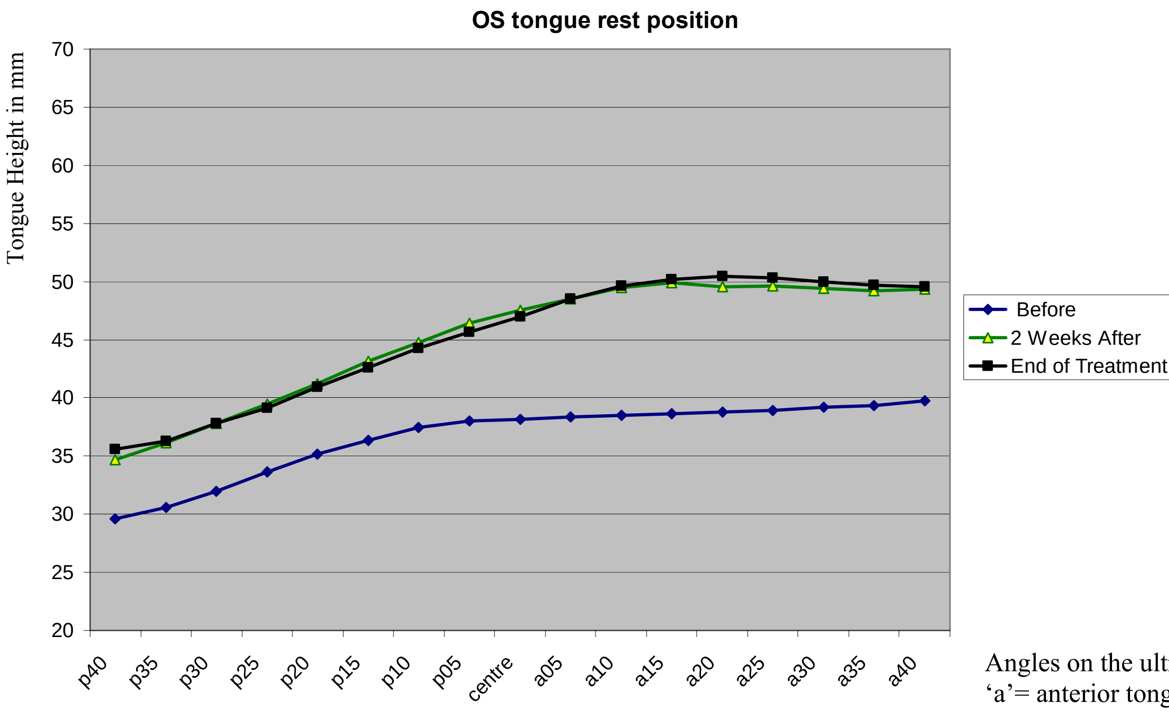
All parts of the tongue were in a higher position at the 2-week examination and this position continued at the end of treatment. For summary of tongue positions see the following tables and Figure (Tables 65, 66; Figure 46).

	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Before MFT	29.6	30.5	31.9	33.6	35.1	36.3	37.4	38.0	38.2	38.3	38.5	38.6	38.8	38.9	39.2	39.3	39.7
2 Weeks After	34.7	36.1	37.8	39.5	41.2	43.2	44.8	46.4	47.5	48.5	49.5	49.9	49.6	49.7	49.4	49.2	49.4
End	35.6	36.2	37.8	39.1	40.9	42.6	44.3	45.6	47.0	48.5	49.6	50.2	50.5	50.3	50.0	49.7	49.6

Table 65. Mean tongue height (mm) at rest for subject OS during different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

Pre - post	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
2 weeks to Before	↑	↑	↑	↑	↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
End to Before	↑	↑	↑	↑	↑	↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑

Table 66. Relative increase or decrease in the tongue height for subject OS at rest during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.



Angles on the ultrasound grid
'a'= anterior tongue
'p'= posterior tongue

Figure 46. Mean tongue height at rest for subject OS during different examinations.

4.6.7. Speech Acceptability

The speech acceptability score for subject OS before appliance insertion was 0.05 ± 0.22. After 2 weeks of appliance insertion, the score was 0.12 ± 0.40 with a mean difference (Before – After) of -0.07 ± 0.34. This change was not statistically significant (P = 0.18). At the end of treatment, the score was 0.17 ± 0.38 with a mean difference of -0.12 ± 0.33. This increase in the acceptability score was statistically significant (P = 0.03; Figure 47). However, the amount of change was minimal. No recording was performed immediately after appliance insertion examination in the MFT group, as the subject was not expected to talk with a removable functional appliance.

Speech acceptability score
0= Normal
1= Mildly affected
2= Moderately affected
3= Severely affected

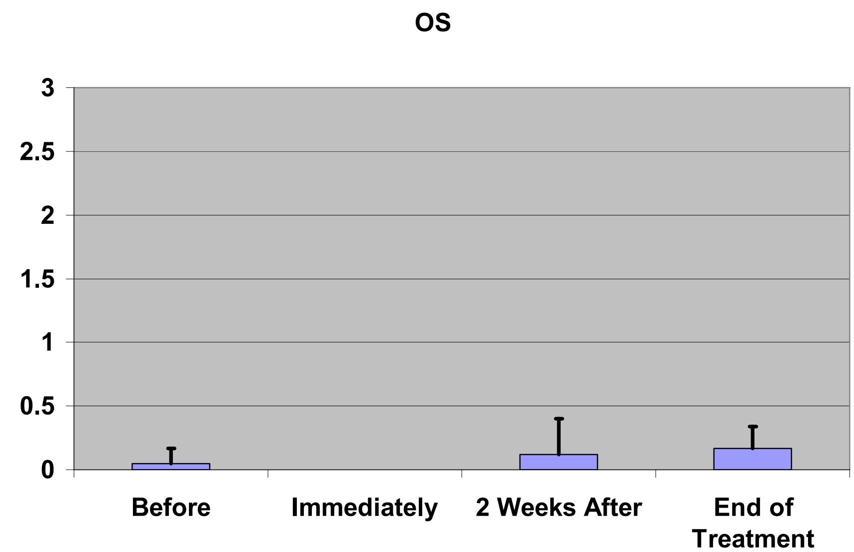


Figure 47. Speech acceptability scores for subject OS during different examinations.

4.7. Study Subject MK

Subject MK had a tongue-thrusting habit. The MFT appliance was inserted when she was 7 years and 6 months of age. The treatment duration was 12 months and 15 days (380 days). MK and the guardian reported that the tongue-thrusting was significantly reduced. The researcher also observed a reduction in tongue-thrusting, even though it was not eliminated at the end of treatment. In addition, a residual anterior open bite was observed. This was marked as partial success. The patient did not show up for the end of treatment ultrasound and voice recordings due to inconvenience reported by the guardian.

4.7.1. Cephalometry

The pre-treatment cephalometric analysis showed that subject MK had an SNA angle of 76.5° and an SNB angle of 70.8°. After removal of the BG appliance, the SNA angle decreased to

74.3° while the SNB decreased to 69.7°. The upper incisor to SN angle was 100.9° prior to treatment and was measured at 93.1° at the end of treatment. Lower incisor to MP increased from 88.9° to 96.2°. The inter-incisal angle remained unchanged. The pre-treatment LFH was 71.8 mm, while after treatment it was 73.5 mm. The upper lip to E line before treatment was 1.1 mm, which did not change to a greater degree at the end of treatment. The lower lip to E line increased from 1.8 mm to 2.9 mm prior to treatment and at the end of treatment, respectively (Tables 67, 68).

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
SNA	76.5	74.3	81.4 ± 3.3
SNB	70.8	69.7	77.7 ± 2.7
ANB	5.8	4.6	3.7 ± 2.1
Upper 1 to SN	100.9	93.1	102.0 ± 2.0
Lower 1 to MP	88.9	96.2	91.4 ± 3.8
Inter-incisal Angle	125.9	126.0	125.5 ± 9.7
Y Axis	71.8	68.2	59.4 ± 3.8

Table 67. Cephalometric angular measurements for subject MK.

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
MD Length	99.7	101.8	97.0 ± 3.9
Mx Unit Length	80.6	82.5	80.0 ± 3.2
Unit Difference	19.1	19.4	17.0
LFH	71.8	73.5	57.0 ± 3.6
Ulip to E line	1.1	1.0	0.0 ± 0.0
Lower Lip to E	1.8	2.9	-2.0 ± 2.0

Table 68. Cephalometric linear measurements (mm) for subject MK.

4.7.2. Study Models

The pre-treatment orthodontic study models for subject MK showed that there was a 3 mm open bite between the maxillary and the mandibular incisors. At the end of the treatment, this was measured as 0.5 mm. Therefore, a total of 2.5 mm reduction of open bite relation was achieved. The overjet was 5 mm which was reduced to 2 mm at the end of treatment. MK had Class I molar relation on both sides with posterior crossbite before treatment. After treatment, the molar relation was ½ cusp Class II on the right side and Class I on the left side with a posterior crossbite. Inter-molar cusp width remained the same at 50 mm after treatment (Table 69).

Measurement	Pre-treatment	Post-treatment
Overjet	5 mm	2 mm
Overbite	-3 mm (open bite)	-0.5 mm (open bite)
Inter-molar cusp width	50 mm	50 mm
Inter-molar width	35.5 mm	37 mm
Molar relationship	Class I both sides, with posterior crossbite	½ cusp Class II right side, Class I left side with posterior crossbite

Table 69. Study model analysis for subject MK.

4.7.3. Clinical photographs

The mean aesthetic score before treatment for subject MK was 3.09 ± 0.43. After treatment, the mean score was reduced to 2.59 ± 0.67. There was a significant reduction of open bite score (P = 0.008) as shown in the clinical photographs below.

MK Before Treatment

MK After Treatment

4.7.4. Tongue Ultrasound Analysis

4.7.5. MK Tongue Function Analysis

4.7.5.1. MK Tongue Height during /a/ Vowel Production

In terms of tongue position, the posterior part of the tongue (p30 to p05) was depressed at the 2-week examination compared to baseline during /a/ vowel production. Unfortunately, we did not have end of treatment ultrasound recording. For a summary of tongue positions see the following tables and Figure (Tables 70, 71; Figure48).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	30.9	31.9	32.9	34.0	35.3	36.6	37.9	39.1	39.8	39.9	39.8	39.4	38.9
2 Weeks After	23.7	24.7	25.9	27.6	29.6	31.9	34.2	36.0	37.5	38.6	39.3	40.0	40.7

Table 70. Mean tongue height (mm) for subject MK during /a/ vowel production at different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

Pre - post	P30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
2 Weeks to Before	↓↓	↓↓	↓↓	↓	↓	↓	↔	↔	↔	↔	↔	↔	↔

Table 71. Relative increase or decrease in the tongue height for subject MK during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

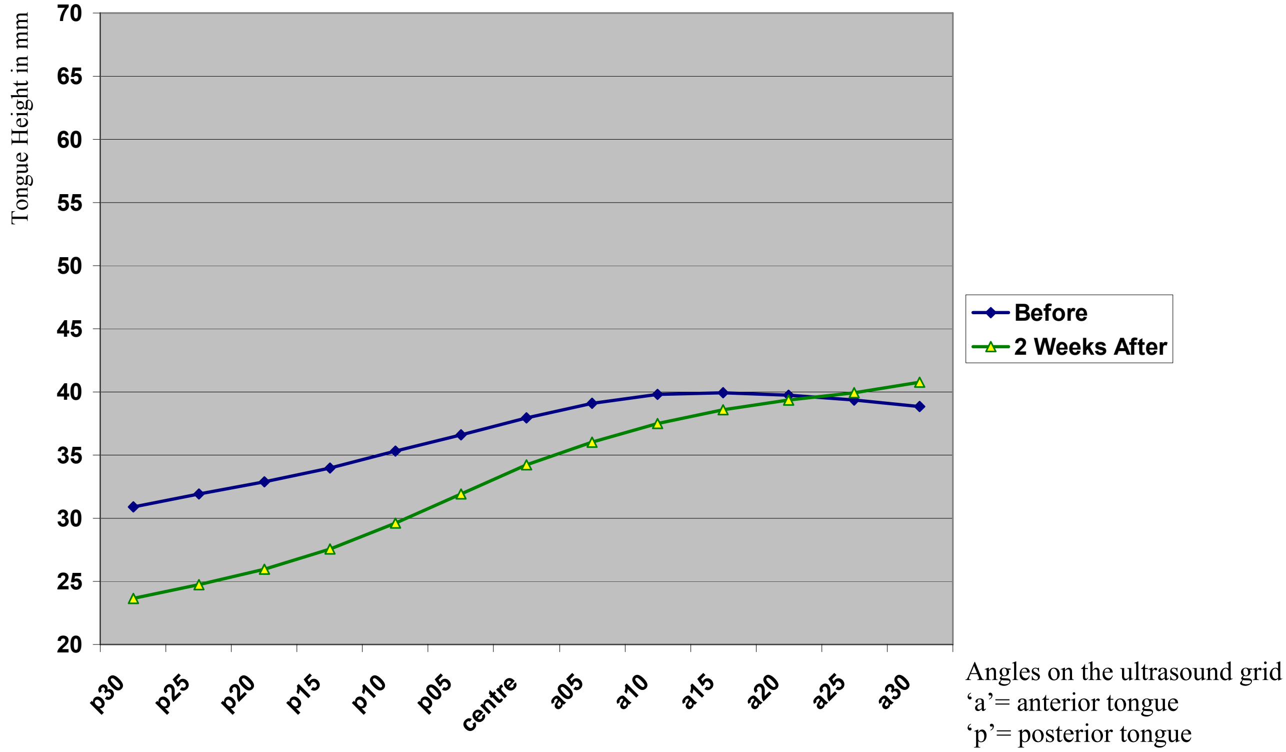


Figure 48. Mean tongue height for subject MK during /a/ vowel production at different examinations.

4.7.5.2. MK Tongue Height during /i/ Vowel Production

In terms of tongue position during /i/ vowel production, the anterior part of the tongue (a05 to a30) was depressed at the 2-week examination compared to before appliance insertion. Unfortunately, we did not have end of treatment ultrasound recording. For a summary of tongue positions see the following tables and Figure (Tables 72, 73; Figure 49).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	24.3	25.5	26.8	28.1	29.9	33.9	41.0	47.9	51.8	53.4	53.8	53.6	53.3
2 Weeks After	22.4	23.8	26.0	28.5	31.4	35.0	38.1	40.5	42.2	43.0	43.6	44.2	44.9

Table 72. Mean tongue height (mm) for subject MK during /i/ vowel production at different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

Pre - post	P30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
2 Weeks to Before	↔	↔	↔	↔	↔	↔	↔	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓

Table 73. Relative increase or decrease in the tongue height for subject MK during different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

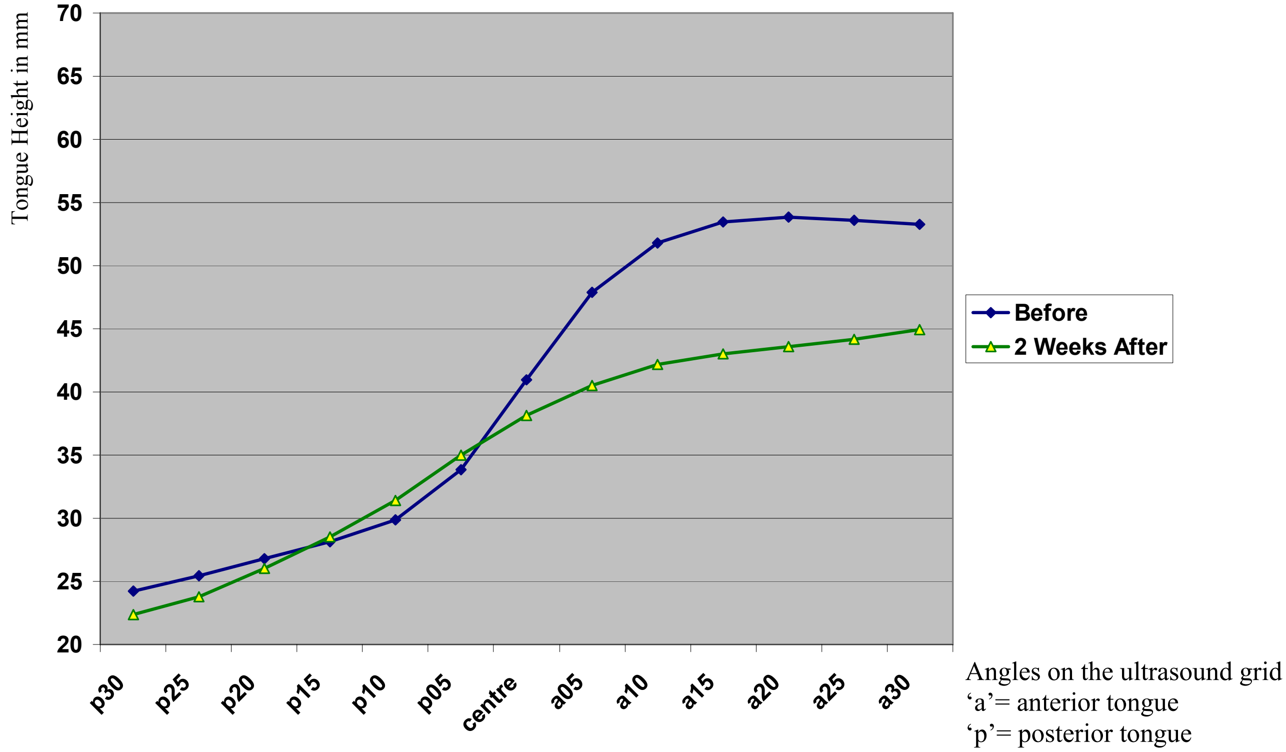


Figure 49. Mean tongue height for subject MK during /i/ vowel production at different examinations.

4.7.5.3. MK Tongue Height during /u/ Vowel Production

The tongue part (p10 to a15) was lower in position at the 2-week examination in comparison to baseline levels (Tables 74, 75; Figure 50). Unfortunately, we did not have end of treatment ultrasound recording of the tongue.

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	25.4	27.0	29.1	31.9	35.5	39.6	43.5	46.0	46.9	46.6	45.4	44.3	43.2
2 Weeks After	23.7	25.1	26.8	28.6	30.8	33.3	35.7	37.9	39.6	41.0	41.8	42.1	42.2

Table 74. Mean tongue height (mm) for subject MK during /u/ vowel production at different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

Pre – post	P30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
2 Weeks – Before	↔	↔	↔	↔	↓	↓	↓↓	↓↓	↓↓	↓	↔	↔	↔

Table 75. Relative increase or decrease in the tongue height for subject MK during different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

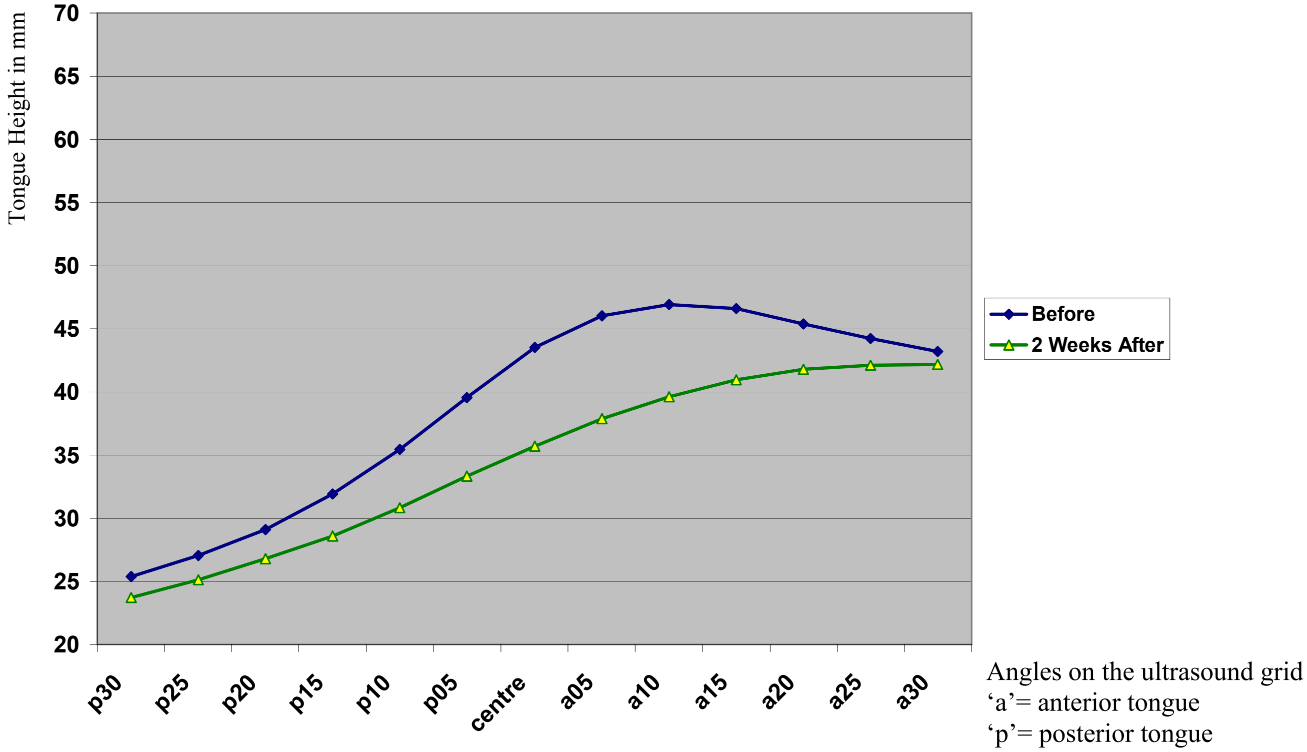


Figure 50. Mean tongue height for subject MK during /u/ vowel production at different examinations.

4.7.6. MK Tongue Rest Position Analysis

The tongue position at rest for subject MK after 2 weeks was close to baseline except for the most posterior part of the tongue (p40 to p30), which was lower in position. Unfortunately, we did not have end of treatment ultrasound recording of the tongue. A summary of tongue positions can be viewed in the following tables and figure (Tables76, 77; Figure 51).

	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Before MFT	34.3	35.0	35.8	36.4	37.4	38.7	40.3	42.0	43.8	46.0	47.9	49.6	50.7	51.4	50.8	50.9	50.8
2 weeks After	28.5	29.5	31.1	32.7	34.4	36.3	38.4	40.4	42.2	43.9	45.5	47.1	48.4	49.3	49.9	49.1	48.3

Table 76. Mean tongue height (mm) at rest for subject MK during different examination. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

Post - Pre	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
2 Weeks to Before	↓	↓	↓	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔

Table 77. Relative increase or decrease in the tongue height for subject MK at rest during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

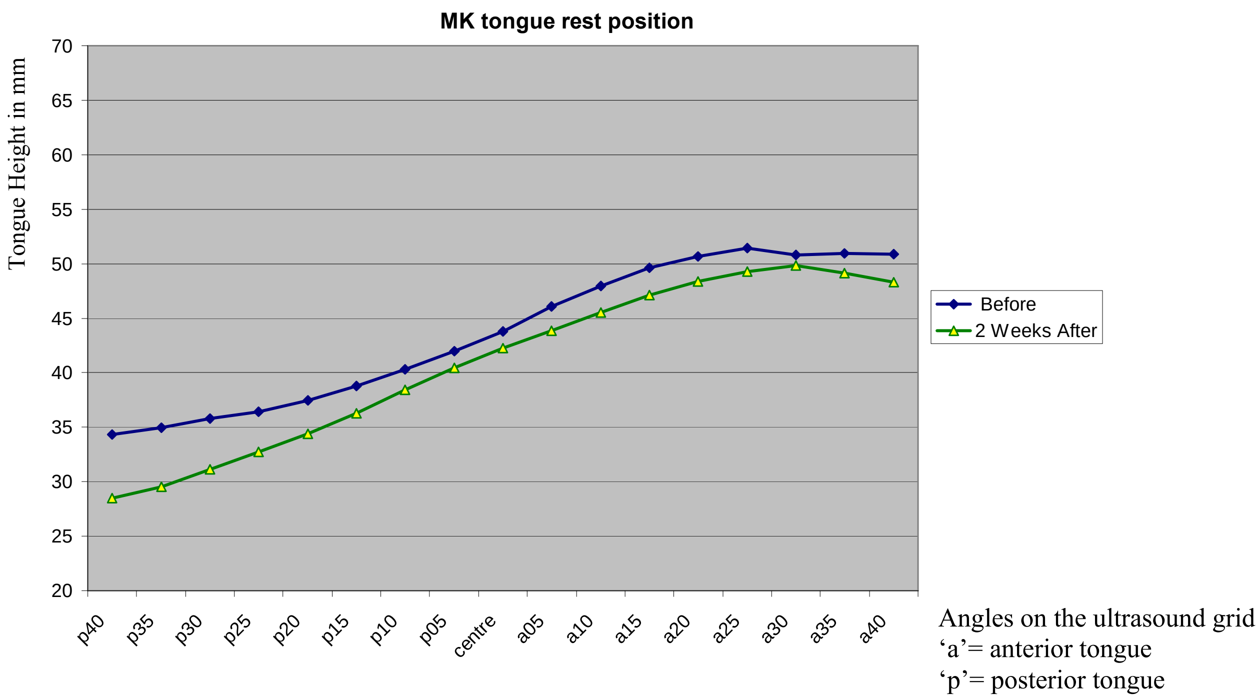


Figure 51. Mean tongue height at rest for subject MK during different examinations.

4.7.7. Speech Acceptability

The mean speech acceptability score for MK before appliance insertion was 0.57 ± 0.55. After 2 weeks, the score was 0.55± 0.59 with a mean difference (Before – After) of 0.02 ± 0.90. This showed a non-significant change from the baseline score (P = 0.86; Figure 52). Unfortunately, no recording is available for the end of treatment.

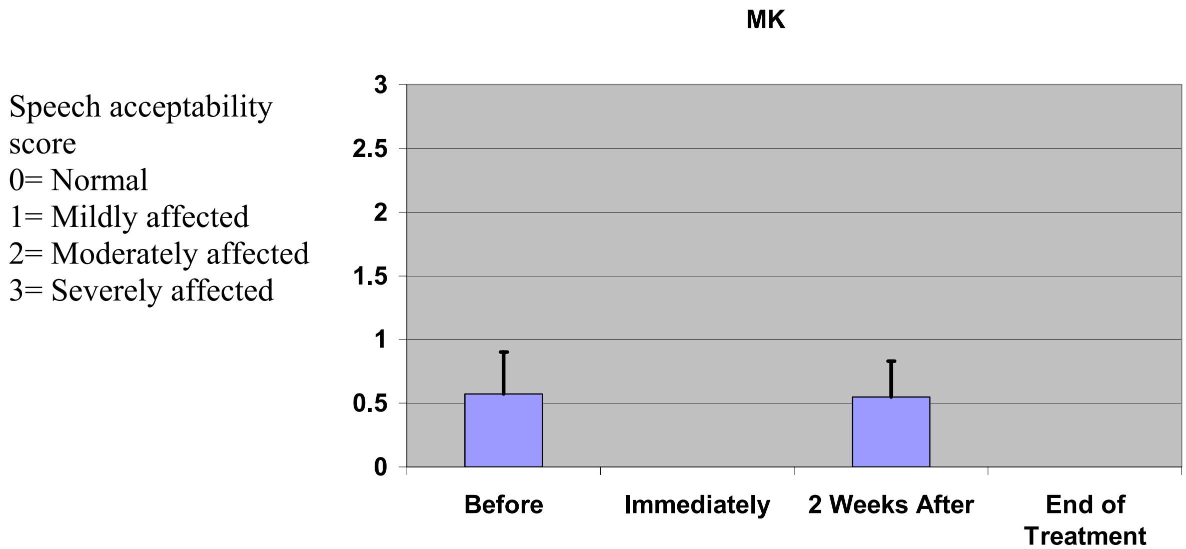


Figure 52. Mean speech acceptability scores for subject MK at different examinations.

4.8. Study Subject MR

Subject MR had a thumb-sucking habit. The MFT appliance was inserted when the subject was 8 years and 1 month of age. The treatment duration was 17 months and 12 days (528 days). The habit was successfully eliminated. It was reported that MR had some compliance issues with wearing the appliance at the beginning of the treatment.

4.8.1. Cephalometry

The pre-treatment cephalometric analysis showed that subject MR had an SNA angle of 86.0° and an SNB angle of 82.7°. On removal of the BG appliance, the SNA angle did not change while the SNB angle was minimally increased. The upper incisor to SN angle was 105.2° which increased to 112.0° at the end of treatment. Lower incisor to MP increased from 92.2° to 97.5°. The inter-incisal angle measured at 131.0° before treatment, which decreased to 121.2° at the end of treatment. The pre-treatment LFH was 59.6 mm whereas after treatment the LFH was 61.0 mm. The upper lip to E line was 2.1 mm before treatment. At the end of the treatment, the upper lip to E line decreased to 0.9 mm. The lower lip to E line decreased from 3.7 mm to 3.5 mm (Tables 78, 79).

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
SNA	86.0	86.0	81.2 ± 3.3
SNB	82.7	83.8	77.3 ± 2.7
ANB	3.2	2.2	3.9 ± 2.1
Upper 1 to SN	105.2	112.0	102.0 ± 2.0
Lower 1 to MP	92.2	97.5	91.4 ± 3.8
Inter-incisal Angle	131.0	121.2	127.1 ± 9.7
Y Axis	56.3	57.2	59.4 ± 3.8

Table 78. Cephalometric angular measurements for subject MR.

Measurement	Pre-treatment	Post-treatment	Standard for age ± SD
MD Length	107.9	113.8	107.0 ± 4.4
Mx Unit Length	86.6	89.4	87.0 ± 3.4
Unit Difference	21.3	24.4	20.0
LFH	59.6	61.0	62.0 ± 4.3
Ulip to E line	2.1	0.9	0.0 ± 0.0
Lower Lip to E	3.7	3.5	-2.0 ± 2.0

Table 79. Cephalometric linear measurements (mm) for subject MR.

4.8.2. Study Models

The pre-treatment orthodontic study models for subject MR showed a 4 mm open bite between the maxillary and the mandibular incisors. At the end of treatment, residual open bite was measured at 0.5 mm. This indicates a 3.5mm reduction in open bite. Conversely, the overjet of 2 mm decreased to 1 mm at the end of treatment. Before treatment, MR had Class I both sides with posterior crossbite. After appliance removal, the molar relation was super Class I on left and Class I on the right side with posterior crossbite. Inter-molar cusp width was measured at 52 mm before appliance insertion. At the end of treatment, the inter-molar cusp width increased to 54.5 mm (Table 80).

Measurment	Pre-treatment	Post-treatment
Overjet	2 mm	1 mm
Overbite	-4 mm (open bite)	-0.5mm (open bite)
Inter-molar cusp width	52 mm	54.5 mm
Inter-molar width	34 mm	36 mm
Molar relationship	super Class I on left, Class I on right with posterior crossbite	super Class I on both sides with posterior crossbite

Table 80. Study model analysis for subject MR.

4.8.3. Clinical Photographs

The mean aesthetic score before treatment for subject MR was 3.18 ± 0.40. After treatment the mean score was reduced to 1.45 ± 0.51. There was a significant reduction of open bite score ($P < 0.001$) as shown in the clinical photographs below.

MR Before Treatment

MR After Treatment

4.8.4. Tongue Ultrasound Analysis

4.8.5. MR Tongue Function Analysis

4.8.5.1. MR Tongue Height during /a/ Vowel Production

During /a/ vowel production, it was noticed that the tongue height after 2 weeks approximated to that before appliance insertion. At the end of treatment, the posterior and the anterior parts of the tongue (p30 to a15) were higher in position compared to baseline (Tables 81, 82; Figure 53).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	27.9	28.4	29.0	29.5	30.3	31.0	32.1	33.2	34.6	36.1	37.6	39.2	41.0
2 Weeks After	31.0	31.5	32.1	32.8	33.5	34.2	35.0	35.9	37.4	38.5	39.6	40.7	42.1
End of Treatment	36.8	37.6	38.2	38.6	39.0	39.5	39.8	40.3	40.6	41.1	41.5	42.2	42.6

Table 81. Mean tongue height (mm) for subject MR during /a/ vowel production at different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

Pre - post	P30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
2 Weeks to Before	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
End to Before	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑	↑	↔	↔	↔

Table 82. Relative increase or decrease in the tongue height for subject MR during different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

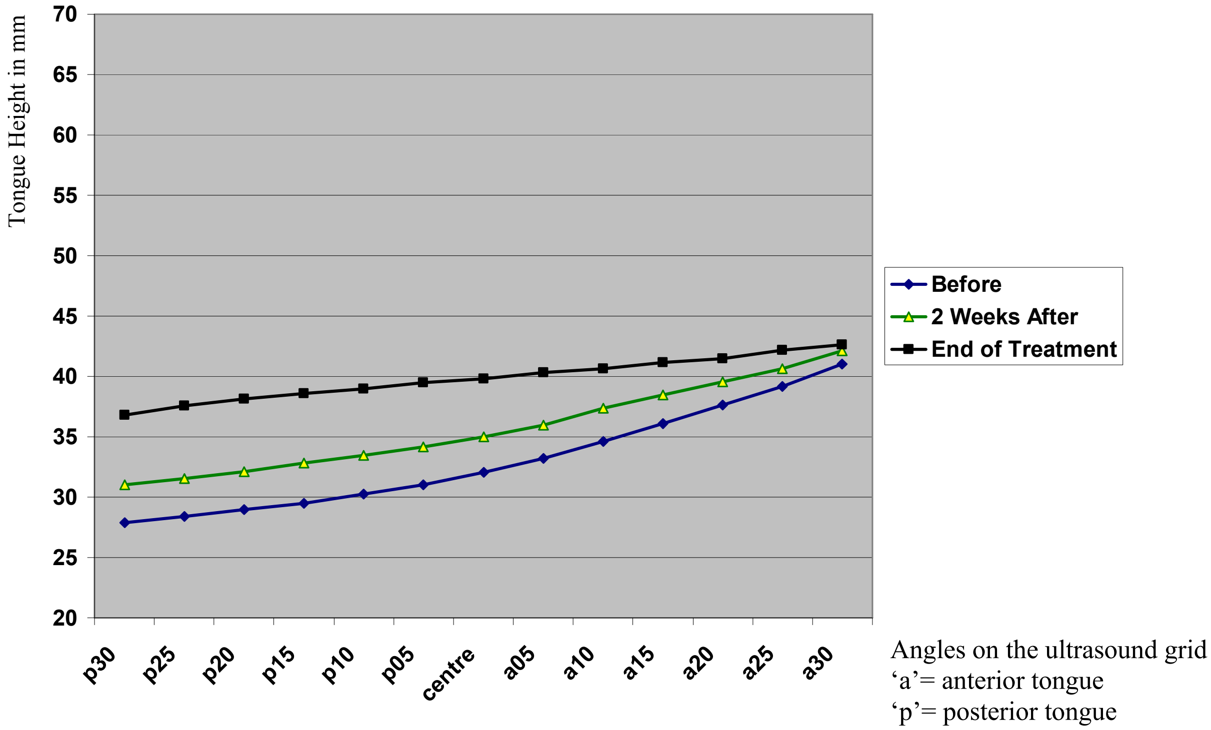


Figure 53. Mean tongue height for the subject MR during /a/ vowel production at different examinations.

4.8.5.2. MR Tongue Height during /i/ Vowel Production

During /i/ vowel production and at the 2-week examination, only part of the tongue (a05 to a15) was higher in position compared to baseline. Moreover, at the end of treatment examination, the posterior and the middle parts of the tongue (p30 to a05) were elevated (Tables 83, 84; Figure 54).

	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	23.9	25.2	26.5	28.6	30.9	33.2	35.8	38.3	40.6	42.7	44.4	45.8	47.3
2 Weeks After	23.9	25.3	26.9	29.3	32.0	35.9	40.1	43.7	46.4	47.6	48.0	48.3	48.4
End of Treatment	28.6	30.0	31.6	33.9	36.1	38.5	40.9	43.1	44.9	46.0	46.7	46.9	46.9

Table 83. Mean tongue height (mm) for subject MR during /i/ vowel production at different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

Pre - post	P30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
2 Weeks to Before	↔	↔	↔	↔	↔	↔	↔	↑	↑	↑	↔	↔	↔
End to Before	↑	↑	↑	↑	↑	↑	↑	↑	↔	↔	↔	↔	↔

Table 84. Relative increase or decrease in the tongue height for subject MR during different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

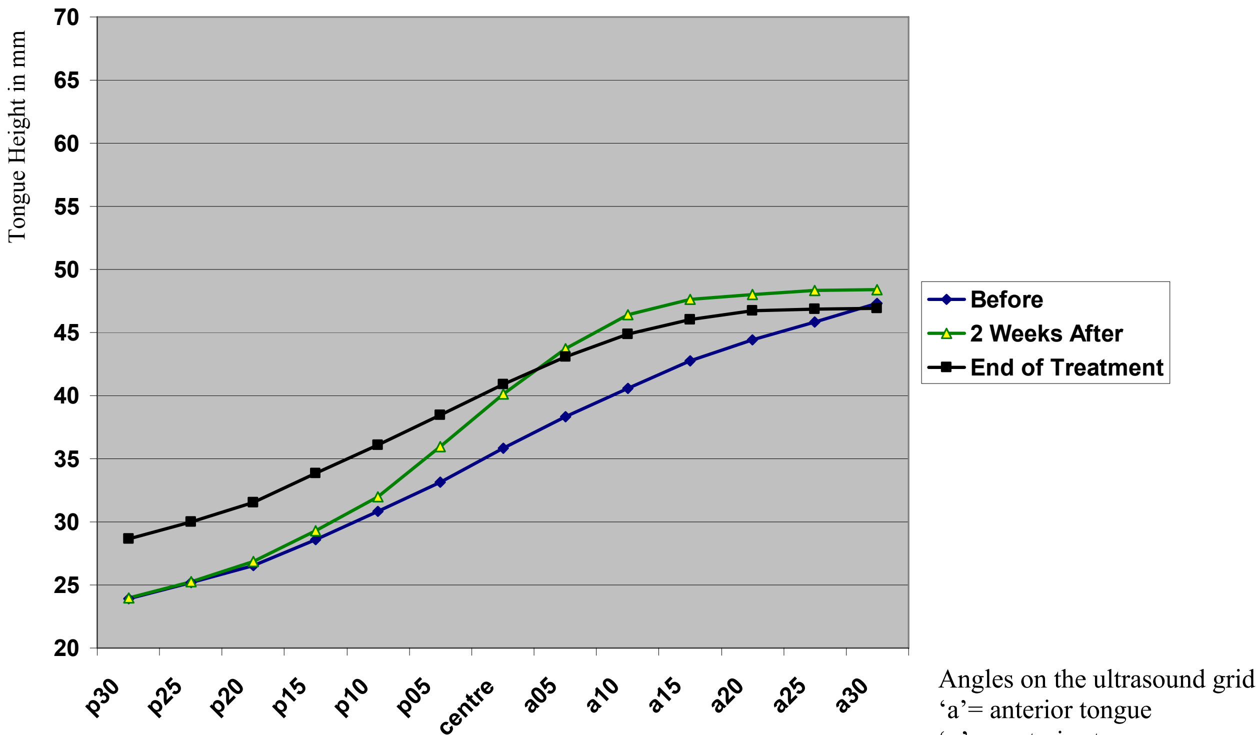


Figure 54. Mean tongue height for subject MR during /i/ vowel production at different examinations.

4.8.5.3. MR tongue Height during /u/ Vowel Production

The tongue height during /u/ vowel production after 2 weeks was close to the position attained before appliance insertion except in the middle part of the tongue (centre to a10), which was elevated. At the end of treatment, the posterior and middle parts of the tongue (p30 to a10) were elevated in position relative to their initial position (Tables 85, 86; Figure 55).

Examination	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
Before MFT	26.4	27.6	29.1	30.5	32.1	33.7	35.3	37.1	38.5	40.0	41.3	42.6	44.4
2 Weeks After	28.1	29.5	31.3	33.3	35.6	37.9	40.3	42.2	43.2	43.6	44.0	44.6	45.4
End of Treatment	33.4	35.0	36.7	38.7	40.5	41.7	42.6	43.3	43.7	43.9	44.3	44.5	44.7

Table 85. Mean tongue height (mm) for subject MR during /u/ vowel production at different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

Pre - post	P30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30
2 Weeks - Before	↔	↔	↔	↔	↔	↔	↑	↑	↑	↔	↔	↔	↔
End - Before	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑	↑	↔	↔	↔	↔

Table 86. Relative increase or decrease in the tongue height for subject MR during different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

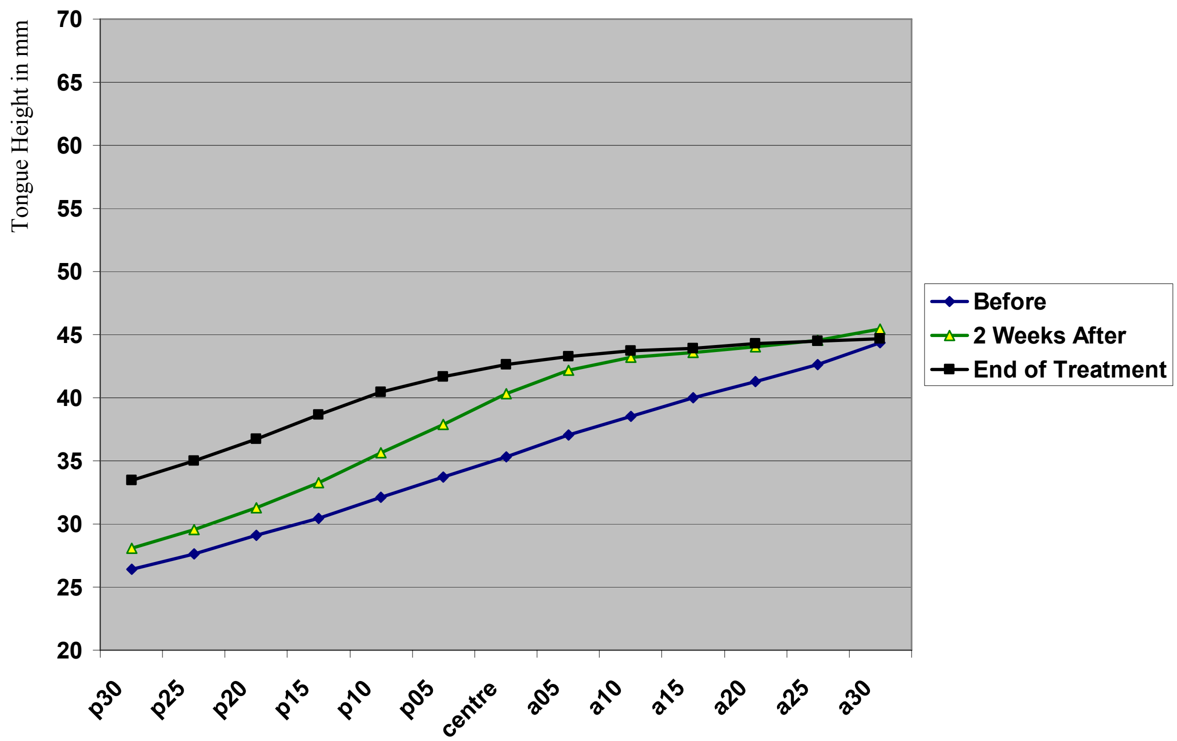


Figure 55. Mean tongue height for subject MR during /u/ vowel production at different examinations.

4.8.6. MR Tongue Rest Position Analysis

The tongue rest position was higher at the 2-week examination and this included almost all parts of the tongue (p30 to a40). The tongue height at the end of treatment was close to that seen after

2 weeks. For summary of tongue positions see the following tables and Figure (Tables 87, 88; Figure 56)

	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
Before MFT	29.1	29.8	30.3	31.1	31.7	32.3	33.0	33.9	34.9	35.6	36.5	37.5	38.5	39.5	40.3	41.3	42.4
2 Weeks After	32.9	33.7	34.8	35.9	37.0	38.2	39.6	40.8	42.3	43.5	44.7	45.7	46.9	47.5	48.1	48.5	49.0
End	32.5	33.2	34.4	35.4	36.9	38.3	39.8	41.2	42.6	44.0	45.4	46.4	47.5	48.4	49.4	50.3	51.3

Table 87. Mean tongue height (mm) at rest for subject MR during different examinations. 'a' denotes 'anterior tongue', 'p' denotes 'posterior tongue'.

Post - Pre	p40	p35	p30	p25	p20	p15	p10	p05	centre	a05	a10	a15	a20	a25	a30	a35	a40
2 Weeks to Before	↔	↔	↑	↑	↑	↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
End to Before	↔	↔	↔	↔	↑	↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑

Table 88. Relative increase or decrease in the tongue height for subject MR at rest during different examinations. 'a' denotes 'anterior tongue' , 'p' denotes 'posterior tongue'.

Angles on the ultrasound grid
'a'= anterior tongue
'p'= posterior tongue

Figure 56. Mean tongue height at rest for subject MR during different examinations.

4.8.7. Speech Acceptability

The mean speech acceptability score for subject MR before appliance insertion was 0.90 ± 0.62. After 2 weeks of appliance insertion, the score was 1.60± 0.70 with a mean difference (Before – After) of -0.69 ± 0.81. This showed a significant increase in the acceptability score (P< 0.001). At the end of treatment, the speech acceptability was close to that of baseline, determined at a score of 0.93 ± 0.51 and a mean difference of -0.02 ± 0.68 that was statistically not significant (P = 0.82; Figure 57). No recording was performed immediately after appliance insertion for reasons stated earlier.

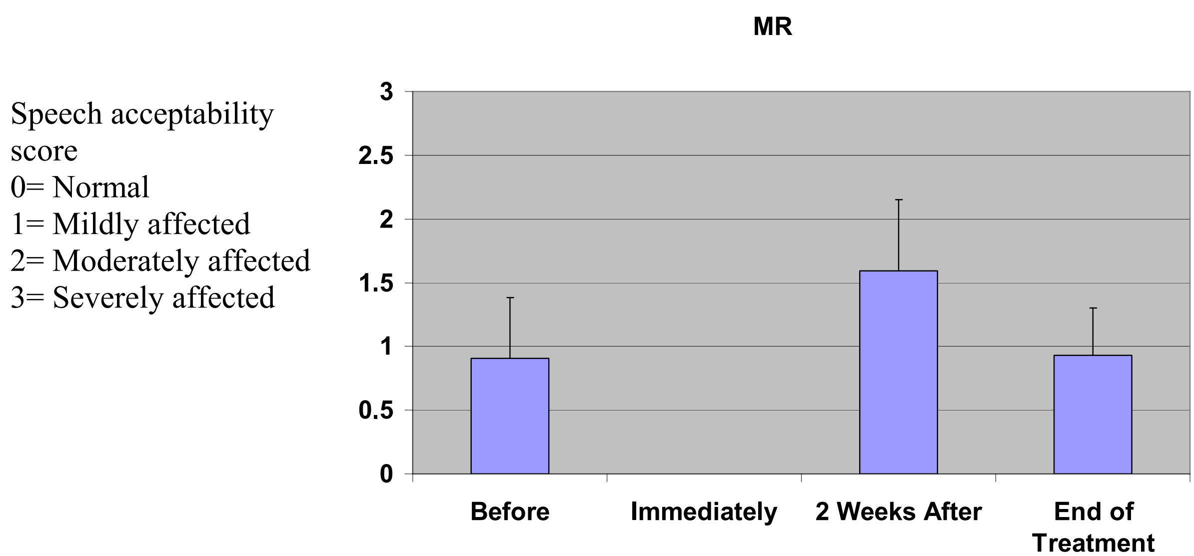


Figure 57. Mean speech acceptability scores for subject MR during different examinations.

4.9. Group Analyses

The mean age for the subjects in the BG group was 11 years and 4 months with a standard deviation of 1.83 years and an age range of 8.9 to 13.2 years. In contrast, the mean age of the MFT group was 10 years with a standard deviation of 2.6 years and an age range of 7.6 to 12.7 years. An unpaired *t* test showed no statistically significant difference between both groups

(1.23 ± 1.61, mean difference ± SD; P = 0.48). The mean total treatment time for the BG group was 9 months and 12 days, while for the MFT group it was 13 months and 7 days.

The BG appliance was effective in breaking the finger-sucking habit for subjects in the BG appliance group. All children completely stopped the finger-sucking habit shortly after insertion of the BG appliance. The MFT appliance showed only partial success in breaking the finger-sucking and tongue-thrusting habits. None of the subjects in the study had reported any difficulty with nasal breathing while the MFT appliance was inserted although this is possible in patients with nasal obstruction.

4.9.1. Cephalometric Analysis for the BG Group

Cephalometric analysis for the BG appliance group was performed as a whole group. The mean differences (After – Before) were calculated and a paired *t* test was performed. There was a reduction in the lower incisor to MP angle of -4.8º ± 4.67 (mean difference ± SD; P = 0.13) while the upper incisors to SN did not change much (-0.075º ± 7.64; P = 0.99). The mean difference in the SNA angle was 1.47º ± 3.00 (P = 0.40) while it was 0.18º ±1.89 (P = 0.87) for the SNB angle; both changes were not statistically significant. The mean difference of Inter-incisal angle was 5.00º ± 11.78 (P = 0.46) this increase was not statistically significant. Skeletal measurement mean differences: MD Length was 4.03 mm ± 0.71 (P = 0.001) and LFH was 1.53 mm ± 0.71 (P = 0.02), which showed significant increase in their lengths. The lower lip to E line mean difference was reduced and was -2.05 mm ± 1.50 (P = 0.07) while the upper lip to E line mean difference was reduced and calculated at -1.4 mm ± 1.26 (P = 0.11). See table 89.

Measurement	Mean Before ± SD	Mean After ± SD	Mean Difference (After – Before) ± SD	P-Value
SNA	84.4 ± 5.6	85.8 ± 3.1	1.47 ± 3.00	0.40
SNB	80.1 ± 4.1	80.2 ± 2.3	0.18 ± 1.89	0.87
ANB	4.28 ± 3.6	5.6 ± 1.4	1.35 ± 2.40	0.34
Upper 1 to SN	114.8 ± 3.3	114.7 ± 6.2	-0.075 ± 7.64	0.99
Lower 1 to MP	101.0 ± 6.3	96.2 ± 3.8	-4.80 ± 4.67	0.13
Inter-incisal angle	109.2 ± 7.4	114.2 ± 6.9	5.00 ± 11.78	0.46
Y Axis	60.9 ± 2.6	60.9 ± 3.4	0.0 ± 1.44	1.00
MD Length	117.3 ± 8.1	121.3 ± 8.4	4.03 ± 0.71	0.001
Mx Unit Length	92.6 ± 3.4	96.6 ± 5.3	3.98 ± 3.20	0.089
Unit Difference	24.7 ± 8.8	24.7 ± 7.0	0.05 ± 2.98	0.98
LFH	71.6 ± 5.8	73.1 ± 6.4	1.53 ± 0.71	0.02
Ulip to E line	0.9 ± 3.4	-0.5 ± 2.9	-1.40 ± 1.26	0.11
Lower Lip to E	6.3 ± 4.9	4.2 ± 3.7	-2.05 ± 1.50	0.07

Table 89. Cephalometric measurements for BG group. Mean before and after treatment and mean difference (After – Before) are shown in the table. Paired *t* test for BG group is calculated.

4.9.2. Cephalometric Analysis for the MFT Group

Cephalometric analysis for the MFT appliance group was performed as a whole group. There was a small change in the lower incisor to MP angle of 0.45º ± 7.02 (mean difference ± SD; P = 0.91) while the upper incisors to SN did not change much (-0.13º ± 6.14; P = 0.97). The mean difference in the SNA angle was -0.63º ± 1.26 (P = 0.40) while it was 0 ± 0.90 (P = 1.00) for the SNB angle; both changes were not statistically significant. The inter-incisal angle showed a non-significant change with the difference being 0.58º ± 7.67 (P = 0.89). Skeletal measurement mean differences: MD Length was 4.63 mm ± 1.82 (P = 0.02) and LFH was 1.65 mm ± 0.56 (P = 0.01), which showed significant increase in their lengths. The Y axis was reduced with a mean difference of -2.50º ± 2.64 (P = 0.15).The lower lip to E line mean difference was -0.35 mm ± 1.10 (P = 0.57) and upper lip to E line mean difference was -0.63 mm ± 0.73 (P = 0.18). See table 90.

Measurement	Mean Before ± SD	Mean After ± SD	Mean Difference (After – Before) ± SD	P-Value
SNA	84.1 ± 6.6	83.5 ± 7.0	-0.63 ± 1.26	0.40
SNB	79.8 ± 6.2	79.8 ± 7.0	0 ± 0.90	1.00
ANB	4.3 ± 2.6	3.7 ± 1.9	-0.63 ± 0.89	0.25
Upper 1 to SN	108.8 ± 6.8	108.6 ± 10.5	-0.13 ± 6.14	0.97
Lower 1 to MP	98.9 ± 15.3	99.3 ± 10.5	0.45 ± 7.02	0.91
Inter-incisal angle	119.7 ± 10.7	120.3 ± 4.5	0.58 ± 7.67	0.89
Y Axis	61.8 ± 7.8	59.3 ± 6.4	-2.50 ± 2.64	0.15
MD Length	111.3 ± 11.2	115.9 ± 12.0	4.63 ± 1.82	0.02
Mx Unit Length	88.8 ± 6.6	91.6 ± 7.1	2.78 ± 1.52	0.04
Unit Difference	22.4 ± 8.2	24.4 ± 6.6	2.0 ± 2.51	0.21
LFH	67.7 ± 9.3	69.3 ± 9.8	1.65 ± 0.56	0.01
Ulip to E line	0.5 ± 2.4	-0.1 ± 1.9	-0.63 ± 0.73	0.18
Lower Lip to E	2.1 ± 1.1	1.8 ± 1.8	-0.35 ± 1.10	0.57

Table 90. Cephalometric measurements for the MFT group. Mean before and after treatment and mean difference (After – Before) are shown in the table. Paired *t* test for is shown.

An unpaired *t* test was performed to compare cephalometric differences between the BG and the MFT appliance groups. There were non-significant differences for all cephalometric measurements between both groups (Table 91).

Measurement	Mean Difference ± SD	P-Value
SNA	2.10 ± 1.63	0.24
SNB	0.18 ± 1.05	0.83
ANB	1.98 ± 1.28	0.17
Upper 1 to SN	0.05 ± 4.90	0.99
Lower 1 to MP	5.25 ± 4.21	0.26
Inter-incisal angle	4.43 ± 7.03	0.55
Y Axis	2.50 ± 1.5	0.15
MD Length	0.60 ± 0.98	0.56
Mx Unit Length	1.20 ± 1.77	0.52
Unit Difference	1.95 ± 1.95	0.36
LFH	0.13 ± 0.45	0.80
Ulip to E line	0.78 ± 0.73	0.30
Lower Lip to E	1.70 ± 0.93	0.12

Table 91. Mean difference between both groups (mean difference BG - mean difference MFT), unpaired *t* test between BG and MFT groups.

4.9.3. Study Model Analysis for the BG Group

For the BG appliance group, mean difference (After – Before) of the study model measurements were calculated and a paired *t* test was performed. The results obtained showed that the mean difference in overjet was -0.50 mm ± 1.29 (P = 0.50) which was non-significant. The mean difference in overbite was 2.38 mm ± 1.89 (P = 0.09), which was non-significant at a 5% level but was significant at a 10% significance level. The Inert-molar cusp width mean difference was 1.38 mm ± 1.25 (P = 0.12) and inter-molar width mean difference was 1.00 mm ± 0.82 (P = 0.09). At a 10% significance level the increase was significant for the inter-molar width (Table 92).

Measurement	Mean Difference ± SD	P-Value
Overjet	-0.50 ± 1.29	0.50
Overbite	2.38 ± 1.89	0.09
Inter-molar cusp width	1.38 ± 1.25	0.12
Inter molar width	1.00 ± 0.82	0.09

Table 92. Mean difference of study model measurements for BG appliance group (After treatment – Before treatment), paired *t* test.

4.9.4. Study Model Analysis for the MFT Group

For the MFT group, mean differences (after treatment – before treatment) of study model measurements were calculated and a paired *t* test was performed. The mean overjet difference was -1.50 mm ± 1.00 (P = 0.06). The overjet reduction was non-significant at a 5% significance level but was significant at a 10% level. The open bite was significantly reduced with a mean difference of 2.13 mm ± 1.25 (P = 0.04). Inert-molar cusp width showed a mean difference of 0.63 mm ± 1.25 (P = 0.39). Inter-molar width increased with a mean difference of 1.00 mm ± 0.91 (P = 0.12) but that was not significant at the 10% level (Table 93).

Measurement	Mean Difference ± SD	P-Value
Overjet	-1.50 ± 1.00	0.06
Overbite	2.13 ± 1.25	0.04
Inter-molar cusp width	0.63 ± 1.25	0.39
Inter-molar width	1.00 ± 0.91	0.12

Table 93. Mean difference of study model measurements for MFT appliance group (After treatment – Before treatment), paired *t* test.

An unpaired *t* test showed that the differences between both groups were not significant. See table 94.

Measurement	Mean Difference ± SD	P-Value
Overjet	1.00 ± 1.15	0.26
Overbite	0.25 ± 1.60	0.83
Inter-molar cusp width	0.75 ± 1.25	0.43
Inter-molar width	0.0 ± 0.87	1.00

Table 94. Study model analysis mean differences between both groups (mean difference BG- mean difference MFT), unpaired *t* test between both groups.

4.9.5. Aesthetic Evaluation of Open Bite for the BG Group

An aesthetic evaluation of open bite reduction was performed for the BG appliance group. The mean score before the BG appliance treatment was 2.86 ± 0.89 (Mean ± SD). After treatment the mean score was reduced to 1.92 ± 0.75. There was a significant reduction of open bite score (P < 0.001) at the end of treatment (Table 95).

4.9.6. Aesthetic Evaluation of Open Bite for the MFT Group

An aesthetic evaluation of open bite reduction was performed for the MFT appliance group. The mean score before the MFT appliance treatment was 2.67 ± 0.94. After treatment the mean score was reduced to 2.03 ± 0.98. There was a significant reduction of open bite score (P < 0.001) at the end of treatment (Table 95).

Group	Mean Score ± SD	P-Value
BG before	2.86 ± 0.89	< 0.001
BG after	1.92 ± 0.75	
MFT before	2.67 ± 0.94	< 0.001
MFT after	2.03 ± 0.98	

Table 95. Aesthetic evaluation of open bite for the BG and MFT groups.

4.9.7. Speech acceptability for the BG group

The speech acceptability results for the BG group indicated that the mean acceptability score for the BG appliance subjects before treatment was 0.63 ± 0.83. Immediately after the BG appliance the acceptability score increased to 2.38 ± 0.65 with a mean difference of -1.76 ± 1.05 ($P < 0.001$). This was a significant increase in speech acceptability score compared to baseline. That increase in acceptability score shows that the speech was more affected. After 2 weeks of BG appliance therapy, the acceptability score was 1.45 ± 0.93 with a mean difference of -0.83 ± 1.22 ($P < 0.001$), which was still a significant increase in the score from baseline. At the end of treatment the score did not return to baseline level and was 1.48 ± 0.72 with a mean difference of -0.93 ± 1.10 ($P < 0.001$). See figure 58 and 59.

4.9.8. Speech acceptability for the MFT group

The speech acceptability results for the MFT appliance group indicated that the mean acceptability score for the MFT group before treatment was 0.60 ± 0.74. After 2 weeks of MFT appliance insertion the acceptability score was 0.82 ± 0.81 with a mean difference of -0.22 ± 0.88 ($P = 0.001$), which was a significant increase in the score. However, at the end of treatment the acceptability score was comparable to baseline level and was 0.54 ± 0.62 with a mean difference of 0.07 ± 0.83 ($P = 0.38$). The change is speech acceptability was not significant compared to the baseline level. See figure 58 and 59. No recording was performed immediately after appliance insertion examination in the MFT group, as the subject was not expected to talk with a removable functional appliance.

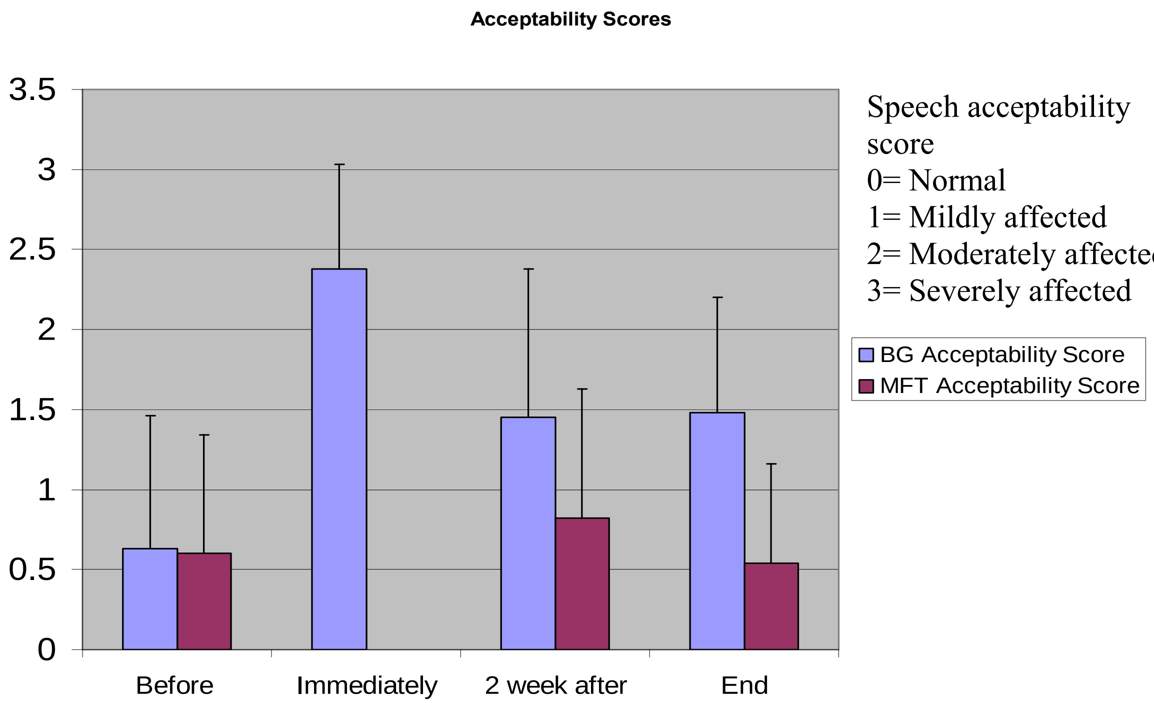


Figure 58. Mean speech acceptability score for the BG and the MFT groups.

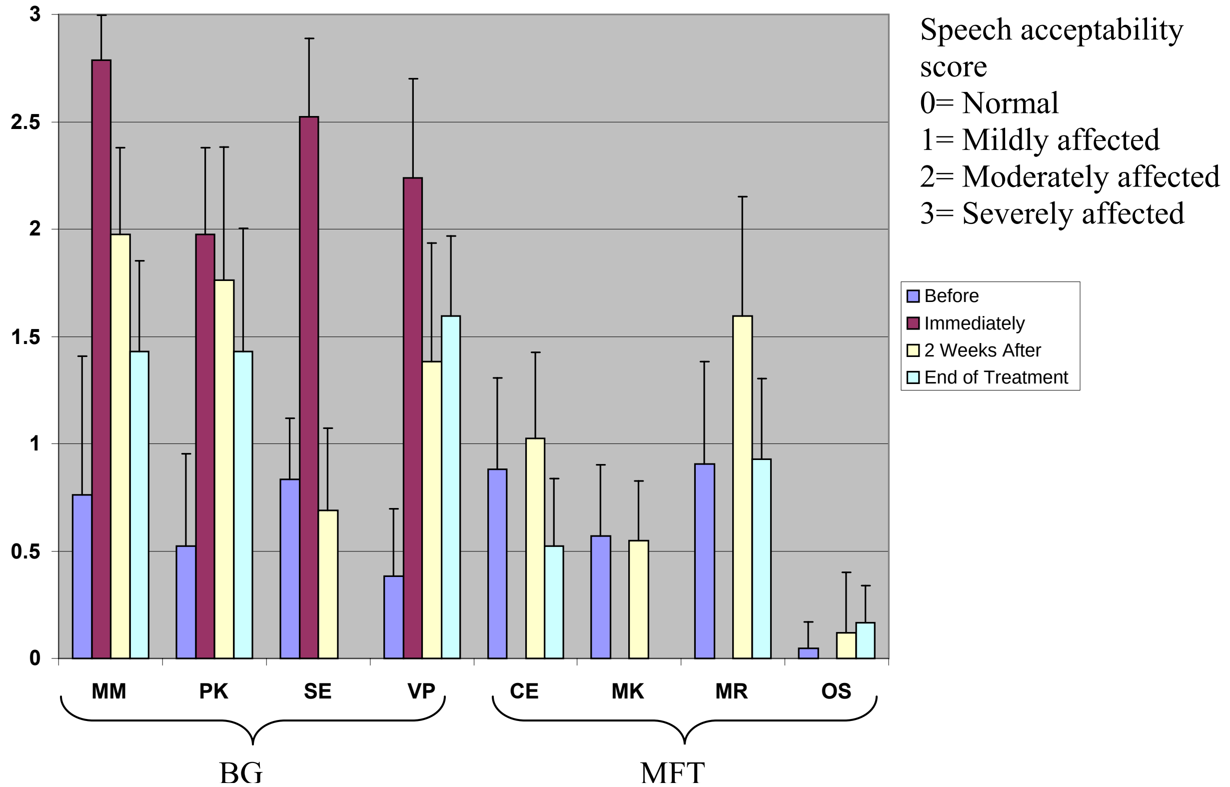


Figure 59. Speech acceptability scores of all subjects in both groups

5. Discussion

This pilot clinical study was a collaboration effort between the Paediatric Dentistry Clinic, Faculty of Dentistry, and the Voice and Resonance Lab, Department of Speech-Language Pathology at the University of Toronto. The longitudinal study involved the use of a novel midsagittal, B-mode ultrasound scanning of the tongue surface to examine tongue physiology at rest and during function following the insertion of two habit-breaking appliances: the conventional BG appliance and the MFT appliance. This study examined speech alterations in response to perturbation caused by these appliances. Upon review of the literature, we found no studies that used ultrasound scanning of the tongue surface to not only monitor changes in tongue position in response to habit-breaking appliances, but also to link these findings to dento-alveolar changes. In addition, there have been no studies that have compared habit-breaking appliances and objectively examined their effects on speech while relating them to dento-alveolar changes and tongue position in children. The current study demonstrates the need for a comprehensive view toward the complex interaction of different factors in the development and treatment of malocclusion. This study showed that anterior open bite was reduced after habit-breaking. The amount of the reduction depended on different factors that will be discussed later. The fixed BG appliance had a long-term detrimental effect on speech acceptability while there was no such effect with the MFT appliance.

5.1. Effects of Age and Duration of Appliance Therapy

The ages of the subjects in this study were between 7 and 13 years. There were several reasons for selecting subjects in this age range: In part, this age range was selected based on previous recommendations for the timing of appliance therapy with respect to cessation of oral habits.

Previous recommendations suggested that there is no need for intervention with appliances until the permanent teeth start to erupt (Gellin, 1978; Haskell & Mink, 1991; Proffit, 2000). In comparison, the current recommendation of the American Academy of Pediatric Dentistry is to monitor oral habits with the possibility of intervention if the habit extends beyond 3 years of age because of the long-term effects on occlusion. In our study, it was not expected that children in this selected age group would stop a prolonged oral habit on their own without intervention. This expectation was based on a study by Larsson (1988), who showed after 1 year that only 2 out of 19 (5%) patients in the control group had quit their prolonged habit in comparison to 11 out of 18 who were treated by a palatal crib appliance. Another reason for choosing subjects in this age range was that our study subjects were required to read from a computer screen during different examinations. As well, the subjects of this age range were expected to be compliant with the instructions and the procedure of ultrasound examination.

The results of this study showed that in general, younger subjects within each gender group had a more favourable result in open bite reduction and were more compliant. Older subjects had comparable results in open bite reduction with a longer treatment period. The duration of treatment is an important factor that affects 2 different outcomes; namely, the success of habit-breaking and the improvement in malocclusion (Cozza et al., 2006; Greenleaf & Mink, 2003; Proffit, 2000). In this study, the mean total treatment time for the BG group was 9 months and 12 days. Previous reports by different researchers have indicated the need to leave the fixed habit-breaking appliances for at least 6 months after the child stops the habit despite the fact that the digit sucking habit is usually broken after the first few days of insertion (Greenleaf & Mink, 2003; Haskell & Mink, 1991; Proffit, 2000). This is to ensure that the child does not return to the habit. Our study was consistent with these previous reports in that the BG appliance was placed for at least 6 months for breaking of the finger-sucking habit. In comparison, the mean total treatment time for the MFT group was 13 months and 7 days. The recommendation of the manufacturer of the MFT is that the appliance should be used for 12 months. As regards treatment time, it is important to ensure that the duration of treatment is adequate to stop the habit. Greenleaf and Mink (2003) reported a 93% success rate in breaking a thumb-sucking habit with a mean total treatment time of 30.3 weeks ± 17.7 weeks. However, Larsson (1988) conducted a study using palatal crib appliances for breaking prolonged oral habits and found that 11 of 18 patients had stopped the habit after 1 year of follow-up from appliance removal. This low success rate was probably due to the fact that the palatal crib appliances were only used for 2.5 months. On the other hand, Haryett et al. (1970) found that palatal crib appliances were more effective in habit-breaking when they were used for 6 and 10 months rather than for only 3 months. They stated that the palatal crib appliance was an effective method in breaking a chronic thumb-sucking habit and they showed only a 9% relapse over a 3-year follow-up.

5.2. Success of the BG Appliance in Habit-breaking and its Advantages

The first objective of this study was to assess the efficacy of the BG and the MFT appliances in habit-breaking. The BG appliance was effective in breaking the finger-sucking habit for subjects in the BG appliance group. All children completely stopped the finger-sucking habit shortly after insertion of the BG appliance. This was due to the nature of the BG appliance as a physical barrier and the fact that the child would not be able to place the thumb or finger inside the mouth to achieve pleasure. This was consistent with a previous report from Greenleaf and Mink (2003) where they reported a 93% success rate of breaking the thumb-sucking habit. However, one subject (SE) at the 2-week examination had distorted the Teflon roller location so that it was inferior in position and was not approximating the rugae area. Although the subject denied any attempt to remove the appliance, this distortion seemed to be the result of an attempt to circumvent the appliance. The appliance was adjusted and then re-inserted and the habit was eliminated. The adjustment of the BG appliance was made easy because of its post and lock-type attachment (fixed-removable appliance) instead of a soldered attachment (Figure 6, page 35). The fixed-removable nature of the appliance allows easy removal of the appliance for examination, modification and reinsertion while reducing the chair time of the patient. If a child stops the habit, the appliance can be easily removed temporarily and re-inserted in case the habit is resumed. The attachment method was different than that described by Greenleaf and Mink (2003) and Haskell and Mink (1991) in which they had the wire soldered to the molar band. The soldered type appliance, in contrast, must be removed, adjusted and re-cemented again. In their study, Greenleaf and Mink (2003) had to reinsert the BG appliance in about 20% of patients for either improper placement or re-fabrication of a broken appliance during treatment. The only disadvantage of the post and lock attachment was the relative flexibility of the wire that held the Teflon roller while the soldered appliance used a more rigid assembly that lead to less vertical movement of the roller. However, the relative flexibility of the roller at the end did not lead to interference with success of the BG appliance in preventing the thumb-sucking habit.

The BG appliance was not effective in breaking the tongue-thrusting habit in 1 subject (PK). Despite the fact that over a 5-month period there was a minimal reduction in open bite observed, the parents and the patient decided to abort treatment and have a palatal crib appliance with posterior bite block inserted to achieve a quicker result. After the palatal crib appliance therapy, the open bite was reduced. No reports have been found in the literature that used the BG appliance in tongue-thrust treatment. However similar appliances, such as palatal plates, have been used to reduce tongue-thrust in Down syndrome patients with good success (Carlstedt, Henningsson, McAllister, & Dahllöf, 2001; Carlstedt et al., 2003). The outcome measures in these studies were clinician's and parent's reports of tongue protrusion during non-speech activities.

Due to the nature of the BG appliance as a fixed appliance there were no reported issues with compliance with habit-breaking in the BG group. The Teflon roller was helpful in distracting the subject from performing the finger-sucking habit and the habit was shortly eliminated after appliance insertion.

5.2.1. Disadvantages of the BG Appliance

The use of the BG appliance involved some discomfort. Subjects reported problems with eating in the first few days of appliance insertion. Also, the BG appliance had a detrimental effect on speech, which will be discussed later. These discomforts, however, were temporary and most of the subjects liked to play with the Teflon roller which had the advantage of distracting the subject from performing the habit. It was noticed that after some time in the intra-oral environment, the Teflon roller became yellowish (Figure 60). This highlights the porosity of the Teflon roller which may attract stains.

Figure 60. BG appliance immediately after insertion and after 4 months inside the mouth. Notice the yellowish discoloration of the Teflon roller after 4 months of insertion.

5.3. Success of the MFT Appliance in Habit-breaking and its Advantages

Generally, the MFT achieved a partial success in habit-breaking for both finger-sucking and tongue-thrust habits, which was related to compliance of the use of the appliance. However, compliance with the MFT was found to improve with time and probably with verbal reinforcement. One advantage of the MFT appliance is that it is a removable appliance and the child removes it at school time where he can read and communicate with peers without any embarrassment. The second advantage is that when the appliance is inserted inside the mouth the child is instructed to keep breathing from the nose which will help to maintain nasal breathing as opposed to oral breathing. None of the subjects in the study had reported any difficulty with nasal breathing while the appliance was inserted although this is possible in patients with nasal obstruction. The third advantage to the MFT appliance is that it is prefabricated and there is no need for the dentist to take impressions or make any adjustments. The appliance can be inserted in the first visit after proper assessment. This will reduce the number of appointments. According to the manufacturer's instructions, the appliance should be worn at least one hour during the day time and while sleeping. The subjects were also instructed to place the appliance when they were engaging in activities that do not require them to speak (e.g., watching television, doing homework) to maximize the time of appliance effect and to counteract compliance issues.

5.3.1. Disadvantages of the MFT Appliance

There were some disadvantages with using the MFT appliance. Although the MFT comes as prefabricated appliance, there was a problem with appliance fit intraorally. The appliance did not have the means to be retentive inside the mouth and the appliance kept dislodging from the child's mouth during sleep. In addition, the appliance is available in only 1 size for children in mixed dentition. It is important for prefabricated appliances to be constructed in different sizes in order to fit different arch dimensions and be suitable for different ages. Both advantages and disadvantages were evident in this study population.

5.4. Cephalometry

5.4.1. Cephalometric Characteristics before Treatment

The pre-treatment cephalometric analysis showed that both groups were comparable. Also, the pre-treatment cephalometric records in both groups showed that prolonged oral habits were associated with a proclination of both the maxillary and mandibular incisors. These findings were consistent with those reported by Afzelius-Alm et al. (2004). They studied lateral cephalograms of 50 children with prolonged thumb-sucking and interestingly they found that the lower incisor to MP angle was increased rather than reduced. Only a minority of cases in that study had retroclined lower incisors. Moore and McDonald (1997) found no difference in lower incisor to mandibular plane angle in children with persistent digit sucking habits compared to control group with no sucking habits, while Proffit (2000) explained that the thumb-sucking habit is usually associated with retroclined lower incisors. The probable cause for the proclination of the lower incisors in our study is that almost all subjects had some degree of open bite. The open bite probably leads to a degree of tongue-thrust which in turn can cause the mandibular incisors to procline. The proclination of both maxillary and mandibular incisors was reflected in a reduction of the inter-incisal angle compared to the standard for that specific age. The skeletal cephalometric measurements that were reported in our study were used to examine whether the 2 study groups were comparable to each other before appliance insertion.

Also the measurements were compared with previous studies reporting cephalometric measurements for habit-breaking therapy (Usumez et al., 2004; Cozza et al., 2006). The skeletal cephalometric measurements were not further discussed as they were peripheral to the main objectives.

5.4.2. Cephalometric Changes after Treatment

All subjects in the BG appliance group had a reduction in the lower incisors to MP angle at the end of treatment, with a mean reduction from 101.0º to 96.2º. In comparison, the MFT group subjects had either a decrease or an increase in the lower incisors to MP angles and hence there was no change in the mean angle for the MFT group at the end of treatment. The unfavourable increase in the lower incisors to MP in 2 subjects was probably caused by the action of the MFT appliance as a functional appliance. Proclination of mandibular incisors is a frequent effect of functional appliance therapy (Proffit, 2000). It therefore seems important to evaluate the inclination of the lower incisor before treatment because of the possibility that the treatment will lead to more proclination of the already proclined lower incisors.

A search of the literature did not find any reports showing the effects of the BG appliance on dento-alveolar relations. However, there are a few studies that examined the effects of different habit-breaking appliances on dentition (Cozza et al., 2006; Cozza et al., 2007; Huang et al., 1990; Villa & Cisneros, 1997). The cephalometric results in the BG group indicate that after habit-breaking the lower incisors retrocline in position. This retroclination (lingual inclination) led to a decrease in the lower lip to E line. Retroclination of lower incisors and decrease in lower lip to E line were consistent to what was reported by Cozza et al. (2006) when they studied the different effects of the modified quad-helix with palatal crib appliance after breaking the thumb-sucking habit.

The upper incisor to SN angle did not change significantly in either the BG or MFT groups at the end of treatment. This finding was not consistent with previous reports that showed retroclination of the maxillary incisors after palatal crib therapy (Cozza et al., 2006; Villa & Cisneros, 1997). Absence of any change in the maxillary incisor to SN angle was a reflection of outliers and the small sample size. It was noticed that 1 subject (VP) in the BG group had the upper incisor to SN angle increase largely instead of decrease because of the hyperactivity of the lower lip that was noticed clinically.

5.5. Study Models

5.5.1. Overbite Changes

Study model analysis showed that open bite was reduced in both groups. The mean total open bite reduction in the BG appliance group was 2.38 mm and 2.13 mm for the MFT group. Cozza et al. (2006) found after an 18 month follow-up that there was a 3.5 mm increase in overbite. In our study the average treatment time was 9 months, which was only half of the treatment time in Cozza's study. On the other hand, Villa and Cisneros (1997) reported a decrease in open bite of 3.7 mm ± 1.9 mm after using a palatal crib appliance in a sample of growing and non growing children over a period of only 4 months. However, the probable cause of the rapid decrease in open bite was due to their selection criteria in which they only included normodivergent class I cases. Although the MFT was used for a longer period than the BG appliance, the mean reduction of open bite was less. This is due to the fact that the BG appliance is a fixed appliance that remains inside the mouth during the entire time of treatment. The results showed that for both groups the reduction of open bite was statistically significant at a 10% significance level. However, there was no significant difference between the two groups.

It appears from study models and cephalometric analyses that the main reduction of the open bite in the BG and the MFT groups were dento-alveolar in nature. Both retroclination and extrusion of anterior incisors were demonstrated from cephalometry and study models. This was consistent with Cozza et al. (2006) in which they showed that the main action of the modified quad-helix was from retroclination of anterior incisors. In addition, some extrusion of maxillary and mandibular incisors was noticed.

Two subjects, 1 from each of the groups (PK, CE), had minimal reduction of open bite at the end of treatment. Cephalometric analysis for those subjects indicated that they had a high LFH. It is important to consider facial hyperdivergency in addition to thumb-sucking habit as risk factors in the development of open bite (Cozza et al., 2005) and poorer treatment outcome. It appears that the amount of open bite self correction is not only dependent on local factors but also on the growth direction of the dentofacial complex. Our findings show that we can monitor habit-breaking by history and by open bite reduction, but the degree of open bite reduction can vary between individuals.

5.5.2. Overjet Changes

The overjet relation in the BG group had minimal change at the end of treatment. This result was similar to a previous report by Villa and Cisneros (1997). The minimal change is due to the increase in the inter-incisal angle caused by the concomitant decrease in the maxillary incisor angle and the decrease in the lower incisor to MP angle. For subjects using the MFT appliance, there was a decrease in overjet at the end of treatment. This overjet reduction was probably caused by the action of the MFT appliance as a functional appliance. While the appliance is being worn, the anterior incisors are placed in an edge to edge relation. The overjet reduction in the MFT group was consistent with a previous report from Usumez et al. (2004).

5.5.3. Inter-molar Distance Changes

The changes in the inter-molar width were consistent with the normal development of the dental arches in children at the mixed dentition stage and were evident in both groups. It was interesting to note that the BG appliance did not interfere with the increase in the inter-arch width.

5.5.4. Summary of Cephalometric and Study Model Analyses

Generally, the main effects revealed by the cephalometry and study model analyses were that the changes were dento-alveolar in nature, mainly open bite reduction. It appears that the changes that were seen in the BG group were related to soft tissue changes e.g., tongue position, lip pressure because no other mechanical force to move the anterior teeth was provided by the BG appliance. In some cases the dento-alveolar changes in response to these soft tissue changes can be quite rapid (subject MM). It might be that the tongue is a maintaining factor in open bite malocclusion and once the tongue is removed from the open bite, the open bite is quickly reduced or eliminated. It is important to keep in mind the structural changes described above when considering the functional and speech changes described later.

5.6. Aesthetic Evaluation of Open Bite Reduction

The aesthetic evaluation of open bite reduction was performed to test whether the clinician subjective evaluation of open bite reduction, and therefore treatment success could be validated in a quasi-quantitative manner. The aesthetic evaluation of open bite indicated that there were significant reductions in open bite for both groups. These results were consistent with objective direct measurements from the study models. As discussed earlier, the mean total open bite reduction in the BG appliance group was 2.38 mm while for the MFT it was 2.13 mm. The raters perceived these reductions as a significant reduction in both groups. However, the raters perceived that the difference between the BG appliance group and the MFT appliance group was not significantly different at the end of treatment. One interesting finding was that in 1 subject (PK) there was only a 0.5 mm reduction in open bite, yet the raters perceived a significant change in the overbite relation. The results of the aesthetic evaluation show that clinician monitoring of the open bite can be a good adjunct to the direct measurement of open bite and probably another method to verify the effectiveness of habit-breaking. It has been shown that clinical evaluation and attractiveness of the degree of the malocclusion done by a clinician although subjective, is reliable and comparable to objective measures of malocclusion assessment (Lewis, Albino, Cunat, & Tedesco, 1982).

5.7. B-mode ultrasound

The B-mode ultrasound imaging used in this study is a unique tool to study the tongue position inside the oral cavity and to the best of our knowledge never been used in such a study. The midsagittal plane of the tongue surface was studied employing the B-mode ultrasound. Longitudinal effects of 2 habit-breaking appliances on tongue height were assessed and objectively measured.

5.7.1. Tongue Function

5.7.1.1. BG Group Tongue Function Analysis

Many patterns of tongue movements were documented for the BG appliance. It was noted that the effects of the BG appliance on the tongue may be evident more during /i/ vowel production. One subject (MM) showed the same pattern at different examinations where the anterior part of the tongue is elevated with the posterior part depressed. Although some adaptation was noticed, the tongue maintained that position throughout the course of the study. In another subject (PK) the anterior tongue was elevated at 1 examination while at another examination the anterior part of the tongue was depressed. In another subject (SE) the anterior part of the tongue was depressed during different examinations. The last subject (VP) did not show significant changes in tongue position during different examinations. The reasons behind this variability need further exploration with a larger sample size.

Generally, the tongue response to the presence of the BG appliance inside the oral cavity was not consistent across subjects. However, the same pattern could be defined in 1 subject (MM) during different vowel productions. This subject had an elevation of the anterior part of the tongue with depression of the posterior part of the tongue that was evident during different examinations and during different vowel productions. This pattern was also present in tongue rest position. As explained earlier, this subject exhibited the quicker and the most favourable result of open bite reduction across all subjects.

It was expected that there would be adaptation of the tongue (tongue approximating the baseline level) to the presence of the appliance over time. However, that was not the case and some subjects did not return to baseline level even after removal of the appliance. This may be due to the fact that the final examination was conducted shortly after removal of the appliances (generally within 1 hour from appliance removal). This explanation is consistent with Cleall's (1965) opinion, where he found that the patterns of tongue movement were erratic when examining the tongue immediately after palatal crib removal. He attributed this erratic tongue movement to the rapid alteration of the sensory cues that the presence of the appliance caused. The probable cause of the inconsistency in tongue behaviour in response to the BG appliance across subjects can be attributed to the true challenge that the appliance caused to the tongue.

The tongue has a defined space inside the oral cavity and any relatively large object in the anterior palate will affect its movement during function.

However, whether the alterations remain stable in the long term remains to be studied. Stable, long-term alterations are likely to benefit stability of the orthodontic treatment.

5.7.1.2. MFT Group Tongue Function Analysis

Generally, the ultrasound analysis of the tongue during function in the MFT appliance group revealed inconsistent patterns between subjects. It was noticed that most of changes in tongue height occur during /i/ vowel production. One subject (MR) showed elevation of the posterior tongue. Two subjects (MK, OS) had the posterior tongue depressed. Another subject (CE) had minimal changes. Adaptation of the tongue was expected to occur after a period of time from appliance use and at the end of treatment, but that did not happen. The tongue at the end of MFT appliance treatment assumed a new position. The lack of adaptation might indicate that the tongue can be trained to assume different positions although this needs to be substantiated in a larger sample and over a longer study period.

5.7.2. Tongue Position at Rest

5.7.2.1. Tongue Position at Rest for the BG Subjects

The tongue position at rest for the BG appliance group did not show a consistent pattern across subjects in response to the BG appliance during different examinations. In 1 subject (MM), the tongue moved in a seesaw pattern with the anterior of the tongue elevated and the posterior depressed. At the end of treatment the posterior part of the tongue remained depressed while the anterior part was less elevated. It was apparent that the tongue assumed a new position at the end of treatment that helped in the rapid and spontaneous dento-alveolar correction that was evident in this subject. Two subjects (PK, VP) in the BG appliance group had the posterior part of the tongue elevated especially at the end of treatment. This pattern might indicate that the tongue is somewhat pushed back inside the oral cavity or retracted in position because of the presence of the Teflon roller that occupies the anterior part of the oral cavity. The last subject (SE) had a depressed tongue immediately after insertion, probably as a reflex, but at the end of treatment the whole tongue approximated the baseline level.

The response of the tongue to the presence of the BG appliance inside the oral cavity was one of the following: firstly, the tongue remained at the same position although it had shown changes immediately after examination. Second, the anterior part of the tongue was either elevated or at the same level with the posterior part elevated indicating that the tongue is pushed backward. Third, the anterior part is elevated and the posterior part is depressed as compensation, or the tongue moves in a seesaw movement. The most favourable position of the tongue at rest is probably where the anterior part of the tongue is elevated with the posterior part either depressed or elevated.

5.7.2.2. Tongue Position at Rest for the MFT Subjects

The tongue position at rest for the MFT appliance subjects showed that at least 2 subjects (OS, MR) had the whole tongue elevated at the 2-week examination and this elevation was retained without adaptation at the end of treatment. This elevation showed that the tongue was in a more favourable position (Cleall, 1965). The sustained elevation of the tongue needs to be investigated for 2 reasons: 1. Does this behaviour indicate that the tongue can be trained to assume a favourable position? 2. Does this indicate that the training of the tongue has a role in open bite correction and may be prognostic of the treatment outcome? If substantiated in a larger study this would mark a significant advancement in the diagnosis and treatment of habit related malocclusions. Presently there are few or no assessments that examine the soft tissues, especially the tongue, which is the key to the successful and stable treatment outcomes. In 1 subject (CE), the anterior part of the tongue was elevated after 2 weeks of appliance insertion but this elevation was not retained and adaptation was noticed. In this subject the increased LFH and the location of the tongue after treatment probably lead to only minimal open bite reduction. Unfortunately, there was not enough information about the last subject in the MFT group because of the lack of final records.

5.8. Effects on Speech

A total of 14 listeners were recruited from the Faculty of Dentistry graduate students and the supporting staff who were native speakers of English. While one might think it is more objective to recruit speech and language specialists to rate the speech of the subject, this is not the case in speech acceptability testing. The purpose of the test is to examine how regular people perceive the level of bizarreness of individual speech and therefore, the speech and language specialist would be more critical in rating individual speech.

It was noticed that for all subjects in both groups except 1 subject (OS), the speech at baseline examination was not perceived by the listeners as completely normal but it was perceived as mildly affected speech. This was due to the fact that all subjects except that subject (OS) had some degree of open bite that affected their speech articulation, especially the /s/ sound that appears as lisping in open bite subjects. This demonstrates an association between open bite malocclusion and speech defects.

It was noticed from the speech acceptability results for the BG group that immediately after BG appliance insertion the speech had deteriorated in all subjects. There was some adaptation to the appliance after 2 weeks, and this adaptation varied between subjects. It was noticed that the speech acceptability score did not drop to baseline at the end of treatment. This demonstrates that persistent residual effects on speech do exist even after cessation of appliance therapy. Unfortunately, there was no additional long-term follow-up. The presence of the roller in a critical location of the anterior palate has a huge impact on the speech because of the perturbation that the roller causes on speech. This was especially evident in some consonant sounds (alveolar consonant e.g., /s/, /t/, /d/). The adverse effects on speech acceptability caused by the BG appliance were evident while the appliance was in place in the mouth and immediately after removal of the appliance. It is expected that adverse speech effects would be eliminated after a period of time after appliance removal. However, speech acceptability was not tested in a long-term in this study.

Previous research has been conducted on the effects of intraoral appliances on articulation. While most of the research studied the effects of intraoral appliances on speech in adults and edentulous patients, they did show that adaptation to these appliances occurs over time (Chierici, Parker, & Hemphill, 1978; Jemt, 1994; Petrović, 1985). Little information is present on adaptation of children to different intraoral appliances. This study shows the relative speech adaptation to fixed intraoral appliances in children over time. It is evident from our results that there was some adaptation to the insertion of the BG appliance overtime but that this adaptation was incomplete and a residual after-effect was present. This is due to the fact that the BG appliance is a relatively large appliance that exists near a critical area for speech articulation, the anterior hard palate. In this study the results obtained from speech acceptability testing for the BG appliance group were consistent with ultrasound data obtained of tongue position during function. The presence of the Teflon roller near the anterior palate represents a continuous challenge to the precision of articulation and tongue movements in children. This finding was not consistent with the previous report by Greenleaf and Mink (2003) in which they explained that the speech difficulties associated with the placement of the BG appliance usually subside within 2 to 3 weeks. However in their study, speech acceptability was not objectively tested.

Alternatively, the MFT group showed a non-significant change in speech acceptability at the end of treatment. It was not expected that the MFT would have systematic effects on speech acceptability since the MFT is kept out from the mouth for most of the day and inserted during sleep time.

In summary, for patients with malocclusion caused by an oral habit or a persistent habit, the pilot study suggests that the BG appliance will probably provide a more consistent result. The BG appliance, however, will have a profound and detrimental impact on the child's speech during the treatment. In this case, the MFT might actually be a viable alternative because the appliance does not affect the child's speech. It is also important to note that in children who have speech problems or are engaged in active treatment for speech problems, a special consideration should be made to the possible detrimental effects of the BG appliance on their treatment. It is important for the treating dentist to consider using a removable appliance like the MFT instead of the BG appliance to break any unfavourable oral habit in children with speech disorders provided there is good compliance with wearing of the appliance. This study demonstrates the importance of not treating oral habits of children in isolation of different factors and the need for an interdisciplinary approach to provide the patient with an individualized treatment plan with the best possible outcomes. It is essential while considering the new recommendation in breaking oral habits in children after the age of 3 years using habit-breaking appliances to take into account the deleterious effects of these appliances on speech during that critical stage of speech development. More research is needed in that area before making any recommendations.

5.9. Factors for a Successful Outcome

The results of this study allow us to build a hypothetical profile of a subject in which successful outcomes for habit-breaking are likely. The possibility of a patient to have successful treatment for habit-breaking and favourable dento-alveolar correction depends on the following:

- Age- It is easier to break unfavourable habits when the child is younger. Also, the spontaneous dento-alveolar correction is much quicker. Developmental age, not chronological age, is important with adolescence being a marker of the growth potential. Girls reach adolescence quicker than boys and this should be considered during treatment. However, fixed appliance therapy at very young age may have unfavourable effects on speech development.
- Appliance type- Fixed appliances are more efficient in habit-breaking than removable appliances. Removable appliances suffer from patient compliance issues of wearing them. Fixed appliances are more predictable in achieving the goal of habit-breaking. In spite of the above mentioned, consideration should be made to the detrimental effects on speech of fixed appliances that need to be placed for a long duration, which is usually more than 6 months.
- Duration of treatment- The longer the duration the appliances are placed, the more favourable are the expected dento-alveolar changes. However, the speed of open bite reduction also depends on other factors e.g., age, type of skeletal growth, tongue position. The duration of treatment depend also on the type of appliance being used. Increasing the treatment duration to a certain limit will have a more predictable habit-

breaking and decrease the likelihood of relapse. Longer durations of treatment may however affect speech to a greater extent.

- Direction of skeletal growth- Favourable skeletal growth is important in achieving the desired dento-alveolar changes. Long lower face height might decrease the chance of spontaneous dento-alveolar correction. The degree of initial skeletal malocclusion also affects the final outcome.
- Tongue position- The position of the tongue at rest might be an important factor in achieving a favourable dento-alveolar correction and in the speed of correction. An elevated anterior tongue or elevated whole tongue is an important factor in dento-alveolar correction. While it is not the only factor, it is an important factor. The tongue position should be maintained in this favourable position during the treatment and possibly following treatment for long-term stability.
- Effect of Speech- Our profile does not predict that subjects who had speech adaptation would have better dento-alveolar correction and better stability after habit-breaking. However, this relation needs to be re-examined in a larger sample.

5.10. Limitation of and Recommendations from the Study

Limitations of this study include the small sample size. The small sample size affected the statistical power of the study. However, this was a longitudinal pilot study and it was difficult to find subjects who were willing to participate in this study voluntarily without compensation. The subjects were expected to undergo different ultrasound examinations of the tongue and multiple speech tasks in addition to the different clinical procedures that were involved during appliance insertion and removal. These procedures were sometimes strenuous to the subjects. Most subjects tolerated very well the ultrasound examination of the tongue and the speech tasks that were performed. The ultrasound examination took around 10- 15 minutes and the speech acceptability test took around 20 minutes. It was essential to keep the head position relatively stable in relation to the ultrasound transducer during the ultrasound examination. The heads of subjects were supported from the back by the investigator's hand. Despite that support, a few of the subjects could not stay still for the relatively long period of time during the ultrasound examinations and examinations had to be repeated. Another limitation is that ultrasound scanning of the tongue gave a 2-dimensional aspect of a 3-dimensional object. It is important to recognize that the tongue is a muscular organ that changes its shape in three dimensions.

A larger study that recruits more subjects would reveal the ultrasonographic patterns following the insertion of different intraoral appliances while considering a specific age category. In addition, it would be helpful to employ ultrasound along with Electromyography to study the tongue and to relate tongue movement to its electromyographic activity. Also, it would be beneficial to study the effects of different fixed orthodontic appliances on speech while relating their effects on tongue movements.

6. Summary and Conclusions

This pilot longitudinal clinical study was conducted jointly by the Paediatric Dentistry Department, Faculty of Dentistry, University of Toronto and the Voice and Resonance Lab, Department of Speech-Language Pathology, University of Toronto. The study revealed the different effects of 2 habit-breaking appliances, the conventional BG appliance and the experimental MFT appliance, on dento-alveolar relations, tongue position at rest and during function, and speech in children with reduced overbite malocclusions associated with oral habits (thumb-sucking habit and tongue-thrust). The study showed the following:

- The BG appliance was successful in breaking the finger-sucking habit while the MFT appliance showed a partial success. Compliance of the MFT appliance use was variable as per patient and parent reports.
- In both groups the open bite malocclusions were reduced at the end of treatment. Dento-alveolar changes were the cause of open bite reduction. Open bite reduction could be used as a criterion to monitor habit-breaking and clinical evaluation might be helpful in assessing that monitoring. In addition to the patient's and parents' report of habit-breaking, this would provide another way to assess the success of habit breaking strategies.
- Pre-treatment cephalometric analysis showed that oral habits were associated with proclination of mandibular incisors. The effect of the BG appliance was retroclination of mandibular incisors.
- In general, there was significant variability in tongue movement in response to both appliances. For the BG group the ultrasound analysis did not show a consistent trend in

tongue movement in response to the appliance. While for the MFT group, a favourable elevation of the tongue at rest position was noticed in some cases.

- The BG appliance had a marked adverse effect on speech acceptability. The speech acceptability score did not return to baseline immediately after the BG appliance removal. Speech acceptability should be followed up after a period of time after appliance removal. The MFT appliance had no systematic effects on speech acceptability.
- Ultrasound imaging of the tongue surface proved to be a helpful non-invasive tool for assessing tongue position at rest and in function. More research is needed to link changes in tongue position and function to different treatment outcomes.

7. References

Afzelius-Alm, A., Larsson, E., Lofgren, C. G., & Bishara, S. E. (2004). Factors that influence the proclination or retroclination of the lower incisors in children with prolonged thumb-sucking habits. *Swedish Dental Journal, 28*(1), 37-45.

Ahlgren, J. (1995). EMG studies of lip and cheek activity in sucking habits. *Swedish Dental Journal, 19*(3), 95-101.

Al-Jobair, A., & Al-Emran, S. E. (2004). Attitudes of Saudi Arabian mothers towards the digit-sucking habit in children. *International Journal of Paediatric Dentistry, 14*(5), 347-354.

American Academy of Pediatric Dentistry Council on Clinical Affairs. (2005). Policy on oral habits. *Pediatric Dentistry, 27*(7 Reference Manual), 40-41.

Andrianopoulos, M. V., & Hanson, M. L. (1987). Tongue-thrust and the stability of overjet correction. *Angle Orthodontist, 57*(2), 121-135.

Anke, B. (1971). The etiology of prolonged thumb sucking. *Scandinavian Journal of Dental Research, 79*(1), 54-59.

Bäckman, B., Grevér-Sjölander, A. -., Bengtsson, K., Persson, J., & Johansson, I. (2007). Children with Down syndrome: Oral development and morphology after use of palatal plates between 6 and 48 months of age. *International Journal of Paediatric Dentistry, 17*(1), 19-28.

Bäckman, B., Grevér-sjölander, A-C., Holm, A-K., & Johansson, I. (2003). Children with Down syndrome: Oral development and morphology after use of palatal plates between 6 and 18 months of age. *International Journal of Paediatric Dentistry, 13*(5), 327-335.

Barber, T. K., & Bonus, H. W. (1975). Dental relationships in tongue-thrusting children as affected by circumoral myofunctional exercise. *Journal of the American Dental Association, 90*(5), 979-988.

Baum, S. R., & McFarland, D. H. (1997). The development of speech adaptation to an artificial palate. *Journal of the Acoustical Society of America, 102*(4), 2353-2359.

Baum, S. R., & McFarland, D. H. (2000). Individual differences in speech adaptation to an artificial palate. *Journal of the Acoustical Society of America, 107*(6), 3572-3575.

Baum, S. R., McFarland, D. H., & Diab, M. (1996). Compensation to articulatory perturbation: Perceptual data. *Journal of the Acoustical Society of America, 99*(6), 3791-3794.

Bayardo, R. E., Mejia, J. J., Orozco, S., & Montoya, K. (1996). Etiology of oral habits. *Journal of Dentistry for Children, 63*(5), 350-353.

Bishara, S. E., Warren, J. J., Broffitt, B., & Levy, S. M. (2006). Changes in the prevalence of nonnutritive sucking patterns in the first 8 years of life. *American Journal of Orthodontics & Dentofacial Orthopedics, 130*(1), 31-36.

Bosnjak, A., Vuievi-Boras, V., Mileti, I., Bozic, D., & Vukelja, M. (2002). Incidence of oral habits in children with mixed dentition. *Journal of Oral Rehabilitation, 29*(9), 902-905.

Bowden, B. D. (1966). A longitudinal study of the effects of digit- and dummy-sucking. *American Journal of Orthodontics, 52*(12), 887-901.

Brauer, J. S., & Holt, T. V. (1965). Tongue thrust classification. *Angle Orthodontist, 35*, 106-112.

Bressmann, T., Ackloo, E., Heng, C-L., & Irish, J. C. (2007). Quantitative three-dimensional ultrasound imaging of partially resected tongues. *Otolaryngology - Head and Neck Surgery, 136*(5), 799-805.

Bressmann, T., Heng, C-L., & Irish, J. C. (2005). Applications of 2D and 3D ultrasound imaging in speech-language pathology. *Journal of Speech-Language Pathology and Audiology, 29*(4), 158-168.

Bressmann, T., Uy, C., & Irish, J. C. (2005). Analysing normal and partial glossectomee tongues using ultrasound. *Clinical Linguistics & Phonetics, 19*(1), 35-52.

Brodle, A. G. (1953). Muscular factors in the diagnosis and treatment of malocclusions. *Angle Orthodontist, 23*(2), 71-77.

Carlstedt, K., Henningsson, G., & Dahllof, G. (2003). A four-year longitudinal study of palatal plate therapy in children with Down syndrome: Effects on oral motor function, articulation and communication preferences. *Acta Odontologica Scandinavica, 61*(1), 39-46.

Carlstedt, K., Henningsson, G., McAllister, A., & Dahllöf, G. (2001). Long-term effects of palatal plate therapy on oral motor function in children with Down syndrome evaluated by video registration. *Acta Odontologica Scandinavica, 59*(2), 63-68.

Castillo-Morales, R. (1998). *Die Orofaziale Oegulationstherapie.* Munich: Pflaum.

Cayley, A. S., Tindall, A. P., Sampson, W. J., & Butcher, A. R. (2000). Electropalatographic and cephalometric assessment of tongue function in open bite and non-open bite subjects. *European Journal of Orthodontics, 22*(5), 463-474.

Cerny, R. (1981). Thumb and finger sucking. *Australian Dental Journal, 26*(3), 167-171.

Chiang, Y. C., Lee, F. P., Peng, C. L., & Lin, C. T. (2003). Measurement of tongue movement during vowels production with computer-assisted B-mode and M-mode ultrasonography. *Otolaryngology - Head & Neck Surgery, 128*(6), 805-814.

Chierici, G., Parker, M. L., & Hemphill, C. D. (1978). Influence of immediate dentures on oral motor skill and speech. *The Journal of Prosthetic Dentistry, 39*(1), 21-28.

Cipes, M. H., Miraglia, M., & Gaulin-Kremer, E. (1986). Monitoring and reinforcement to eliminate thumbsucking. *Journal of Dentistry for Children, 53*(1), 48-52.

Cleall, J. F. (1965). Deglutition: A study of form and function. *American Journal of Orthodontics, 51*, 566-594.

Cohen, A. M., & Vig, P. S. (1976). A serial growth study of the tongue and intermaxillary space. *Angle Orthodontist, 46*(4), 332-337.

Cooper, N. S. (1973). Myofunctional therapy. *International Journal of Orthodontics, 11*(3), 81-87.

Cozza, P., Baccetti, T., Franchi, L., & McNamara, J. A.,Jr. (2006). Treatment effects of a modified quad-helix in patients with dentoskeletal open bites. *American Journal of Orthodontics & Dentofacial Orthopedics, 129*(6), 734-739.

Cozza, P., Baccetti, T., Franchi, L., Mucedero, M., & Polimeni, A. (2005). Sucking habits and facial hyperdivergency as risk factors for anterior open bite in the mixed dentition. *American Journal of Orthodontics & Dentofacial Orthopedics, 128*(4), 517-519.

Cozza, P., Mucedero, M., Baccetti, T., & Franchi, L. (2007). Treatment and posttreatment effects of quad-helix/crib therapy of dentoskeletal open bite. *Angle Orthodontist, 77*(4), 640-645.

Curzon, M. E. (1974). Dental implications of thumb-sucking. *Pediatrics, 54*(2), 196-200.

da Silva Filho, O. G., Gomes Goncalves, R. J., & Maia, F. A. (1991). Sucking habits: Clinical management in dentistry. *Journal of Clinical Pediatric Dentistry, 15*(3), 137-156.

Dahan, J. S., & Lelong, O. (2003). Effects of bite raising and occlusal awareness on tongue thrust in untreated children. *American Journal of Orthodontics & Dentofacial Orthopedics, 124*(2), 165-172.

Dubner, R., Sessle B. J., Storey A. T. (1978). *The Neural Basis of Oral and Facial Function*. (pp. 348-376). New York: Plenum Press.

Egermark-Eriksson, I. (1982). Malocclusion and some functional recordings of the masticatory system in Swedish schoolchildren. *Swedish Dental Journal, 6*(1), 9-20.

Ellingson, S. A., Miltenberger, R. G., Stricker, J. M., Garlinghouse, M. A., Roberts, J., Galensky, T. L., et al. (2000). Analysis and treatment of finger sucking. *Journal of Applied Behavior Analysis, 33*(1), 41-52.

Engelke, W. G., Mendoza, M., & Repetto, G. (2006). Preliminary radiographic observations of the tongue-repositioning manoeuvre. *European Journal of Orthodontics, 28*(6), 618-623.

Farsi, N. M., & Salama, F. S. (1997). Sucking habits in Saudi children: Prevalence, contributing factors and effects on the primary dentition. *Pediatric Dentistry, 19*(1), 28-33.

Flege, J. E., Fletcher, S. G., & Homiedan, A. (1988). Compensating for a bite block in /s/ and /t/ production: Palatographic, acoustic, and perceptual data. *Journal of the Acoustical Society of America, 83*(1), 212-228.

Fletcher, S. G., Casteel, R. L., & Bradley, D. P. (1961). Tongue-thrust swallow, speech articulation, and age. *Journal of Speech & Hearing Disorders, 26*, 201-208.

Fowler, C. A., & Turvey, M. T. (1980). Immediate compensation in bite-block speech. *Phonetica, 37*(5-6), 306-343.

Friman, P. C., Barone, V. J., & Christophersen, E. R. (1986). Aversive taste treatment of finger and thumb sucking. *Pediatrics, 78*(1), 174-176.

Friman, P. C., & Hove, G. (1987). Apparent covariation between child habit disorders: Effects of successful treatment for thumb sucking on untargeted chronic hair pulling. *Journal of Applied Behavior Analysis, 20*(4), 421-425.

Friman, P. C. (1988). Eliminating chronic thumb sucking by preventing a covarying response. *Journal of Behavior Therapy and Experimental Psychiatry, 19*(4), 301-304.

Friman, P. C., McPherson, K. M., Warzak, W. J., & Evans, J. (1993). Influence of thumb sucking on peer social acceptance in first-grade children. *Pediatrics, 91*(4), 784-786.

Fuhrmann, R. A., & Diedrich, P. R. (1994). B-mode ultrasound scanning of the tongue during swallowing. *Dento-Maxillo-Facial Radiology, 23*(4), 211-215.

Fujiki, T., Inoue, M., Miyawaki, S., Nagasaki, T., Tanimoto, K., & Takano-Yamamoto, T. (2004). Relationship between maxillofacial morphology and deglutitive tongue movement in patients with anterior open bite. *American Journal of Orthodontics & Dentofacial Orthopedics, 125*(2), 160-167.

Fukuta, O., Braham, R. L., Yokoi, K., & Kurosu, K. (1996). Damage to the primary dentition resulting from thumb and finger (digit) sucking. *Journal of Dentistry for Children, 63*(6), 403-407.

Gellin, M. E. (1978). Digital sucking and tongue thrusting in children. *Dental Clinics of North America, 22*(4), 603-619.

Graber, T. M. (1958). The finger-sucking habit and associated problems. *Journal of Dentistry for Children (Chicago, Ill.), 25*, 145.

Graber, T. M. (1963). The "three M's": Muscles, malformation, and malocclusion. *American Journal of Orthodontics & Dentofacial Orthopedics., 49*(6), 418-450.

Graber, T. M. (2000). In Graber T. M., Vanarsdall R. L. (Eds.), *Orthodontics: Current Principles and Techniques* (3rd ed.). (pp.26, 27). St. Louis: Mosby.

Greenleaf, S., & Mink, J. (2003). A retrospective study of the use of the bluegrass appliance in the cessation of thumb habits. *Pediatric Dentistry, 25*(6), 587-590.

Hanson, M. L., Barnard, L. W., & Case, J. L. (1969). Tongue-thrust in preschool children. *American Journal of Orthodontics, 56*(1), 60-69.

Haryett, R. D., Hansen, F. C., & Davidson, P. O. (1970). Chronic thumb-sucking. A second report on treatment and its psychological effects. *American Journal of Orthodontics, 57*(2), 164-178.

Haskell, B. S., & Mink, J. R. (1991). An aid to stop thumb sucking: The "bluegrass" appliance. *Pediatric Dentistry, 13*(2), 83-85.

Heydecke, G., McFarland, D. H., Feine, J. S., & Lund, J. P. (2004). Speech with maxillary implant prostheses: Ratings of articulation. *Journal of Dental Research, 83*(3), 236-240.

Hopkin, G. B. (1967). Neonatal and adult tongue dimensions. *The Angle Orthodontist, 37*(2), 132-133.

Huang, G. J., Justus, R., Kennedy, D. B., & Kokich, V. G. (1990). Stability of anterior openbite treated with crib therapy. see comment. *Angle Orthodontist, 60*(1), 17-24.

Jacobs, R., Manders, E., Van Looy, C., Lembrechts, D., Naert, I., & Van Steenberghe, D. (2001). Evaluation of speech in patients rehabilitated with various oral implant-supported prostheses. *Clinical Oral Implants Research, 12*(2), 167-173.

Janson, S., & Fakhouri, H. (1993). Dental health in suburban Jordanian preschool children. *Swedish Dental Journal, 17*(3), 123-127.

Jemt, T. (1994). Fixed implant-supported prostheses in the edentulous maxilla. A five-year follow-up report. *Clinical Oral Implants Research, 5*(3), 142-147.

Kawamura, M., Nojima, K., Nishii, Y., & Yamaguchi, H. (2003). A cineradiographic study of deglutitive tongue movement in patients with anterior open bite. *Bulletin of Tokyo Dental College, 44*(3), 133-139.

Kellum, G. D., Gross, A. M., Hale, S. T., Eiland, S., & Williams, C. (1994). Thumbsucking as related to placement and acoustic aspects of /s, z/ and lingual rest postures. *International Journal of Orofacial Myology, 20*, 4-9.

Kenny, D. J., Casas, M. J., & McPherson, K. A. (1989). Correlation of ultrasound imaging of oral swallow with ventilatory alterations in cerebral palsied and normal children: Preliminary observations. *Dysphagia, 4*(2), 112-117.

Kharbanda, O. P., Sidhu, S. S., Sundaram, K., & Shukla, D. K. (2003). Oral habits in school going children of Delhi: A prevalence study. *Journal of the Indian Society of Pedodontics & Preventive Dentistry, 21*(3), 120-124.

Kravitz, H., & Boehm, J. J. (1971). Rhythmic habit patterns in infancy: Their sequence, age of onset, and frequency. *Child Development, 42*(2), 399-413.

Larsson, E. (1971). Dummy- and finger-sucking habits with special attention to their significance for facial growth and occlusion. 1. incidence study. *Svensk Tandlakaretidskrift, 64*(10), 667-672.

Larsson, E. (1988). Treatment of children with a prolonged dummy or finger-sucking habit. *European Journal of Orthodontics, 10*(3), 244-248.

Larsson, E. (1994). Artificial sucking habits: Etiology, prevalence and effect on occlusion. *International Journal of Orofacial Myology, 20*, 10-21.

Larsson, E., Ogaard, B., & Lindsten, R. (1992). Dummy- and finger-sucking habits in young Swedish and Norwegian children. *Scandinavian Journal of Dental Research, 100*(5), 292-295.

Larsson, E., & Ronnerman, A. (1981). Clinical crown length in 9-, 11- and 13-year-old children with and without finger-sucking habit. *British Journal of Orthodontics, 8*(4), 171-173.

Lassen, M. K., & Fluet, N. R. (1978). Elimination of nocturnal thumbsucking by glove wearing. *Journal of Behavior Therapy and Experimental Psychiatry, 9*(1), 85.

Lauder, R., & Muhl, Z. F. (1991). Estimation of tongue volume from magnetic resonance imaging. *Angle Orthodontist, 61*(3), 175-184.

Lebrun, Y. (1985). Tongue thrust, tongue tip position at rest, and sigmatism: A review. *Journal of Communication Disorders, 18*(4), 305-312.

Levy, D. M. (1937). Thumb- or fingersucking from the psychiatric angle. *The Angle Orthodontist, 7*(2), 100-103.

Lewis, E. A., Albino, J. E., Cunat, J. J., & Tedesco, L. A. (1982). Reliability and validity of clinical assessments of malocclusion. *American Journal of Orthodontics, 81*(6), 473-477.

Lindner, A., & Modeer, T. (1989). Relation between sucking habits and dental characteristics in preschoolchildren with unilateral cross-bite. *Scandinavian Journal of Dental Research, 97*(3), 278-283.

Luffingham, J. (1970). A study of the buccal forces exerted upon teeth during finger-sucking. *Dental Practitioner & Dental Record, 21*(3), 95-99.

Luke, L. S., & Howard, L. (1983). The effects of thumbsucking on orofacial structures and speech: A review. *Compendium of Continuing Education in Dentistry, 4*(6), 575-579.

Mason, R. M., Ferketic, M. M., Gideon, S. S., Hanson, M. L., Shelton, R. L., Wiedel, I. M., et al. (1989). Ad hoc committee on labial-lingual posturing function. *ASHA, 31*(11), 92-94.

Massler, M., & Wood, A. W. S. (1949). Thumb-sucking. *Journal of Dentistry for Children, 16*, 1-9.

McFarland, D. H., & Baum, S. R. (1995). Incomplete compensation to articulatory perturbation. *Journal of the Acoustical Society of America, 97*(3), 1865-1873.

McFarland, D. H., Baum, S. R., & Chabot, C. (1996). Speech compensation to structural modifications of the oral cavity. *Journal of the Acoustical Society of America, 100*(2 I), 1093-1104.

Melsen, B., Stensgaard, K., & Pedersen, J. (1979). Sucking habits and their influence on swallowing pattern and prevalence of malocclusion. *European Journal of Orthodontics, 1*(4), 271-280.

Modeer, T., Odenrick, L., & Lindner, A. (1982). Sucking habits and their relation to posterior cross-bite in 4-year-old children. *Scandinavian Journal of Dental Research, 90*(4), 323-328.

Moore, M. B., & McDonald, J. P. (1997). A cephalometric evaluation of patients presenting with persistent digit sucking habits. *British Journal of Orthodontics, 24*(1), 17-23.

Moss, M. L. (1962). The functional matrix. In B. Kraus, & R. Riedel (Eds.), *Vistas in Orthodontics.* (pp. 85-98). Philadelphia: Lea & Febiger.

Moyers, R. E. (1988). In Moyers R. E. (Ed.), *Handbook of Orthodontics* (4th ed. -- ed.). (pp. 94, 154-155). Chicago: Year Book Medical Publishers.

Nahoum, H. I. (1975). Anterior open-bite: A cephalometric analysis and suggested treatment procedures. *American Journal of Orthodontics, 67*(5), 523-521.

Ohkiba, T., & Hanada, K. (1989). Adaptive functional changes in the swallowing pattern of the tongue following expansion of the maxillary dental arch in subjects with and without cleft palate. *Cleft Palate Journal, 26*(1), 21-30.

Osberger, M. J., & McGarr, N. S. (1982). Speech production characteristics of the hearing impaired. In N. J. Lass (Ed.) Speech and language: Advances in basic research and practice. (pp. 221-283). New York: Academic.

Peng, C. L., Jost-Brinkmann, P. G., Miethke, R. R., & Lin, C. T. (2000). Ultrasonographic measurement of tongue movement during swallowing. *Journal of Ultrasound in Medicine, 19*(1), 15-20.

Peng, C-L., Jost-Brinkmann, P-G., Yoshida, N., Miethke, R-R., & Lin, C-T. (2003). Differential diagnosis between infantile and mature swallowing with ultrasonography. *European Journal of Orthodontics, 25*(5), 451-456.

Petrović, A. (1985). Speech sound distortions caused by changes in complete denture morphology. *Journal of Oral Rehabilitation, 12*(1), 69-79.

Proffit, W. R. (1978). Equilibrium theory revisited: Factors influencing position of the teeth. *Angle Orthodontist, 48*(3), 175-186.

Proffit, W. R., & Ackerman, J. L. (1994). Diagnosis and treatment planning in orthodontics. In T. M. Graber, & R. L. Vanarsdall (Eds.), *Orthodontics: Current Principles and Techniques* (1994th ed.,). (pp. 42-44). St Louis: Mosby-Year Book.

Proffit, W. R., Chastain, B. B., & Norton, L. A. (1969). Linguopalatal pressure in children. *American Journal of Orthodontics, 55*(2), 154-166.

Proffit, W. R., & Mason, R. M. (1975). Myofunctional therapy for tongue-thrusting: Background and recommendations. *Journal of the American Dental Association, 90*(2), 403-411.

Proffit, W. R., & White, R. P. (Eds.). (1991). *Long face problems. Surgical Orthodontic Treatment*. (pp. 381-427). St Louis: Mosby-Year Book.

Proffit, W. R. (2000). In Fields H. W. (Ed.), *Contemporary Orthodontics* (3rd ed.) (pp. 134-137, 364-384, 445-447). St. Louis: Mosby.

Rankin, E. A., Jabaley, M. E., Blair, S. J., & Fraser, K. E. (1988). Acquired rotational digital deformity in children as a result of finger sucking. *Journal of Hand Surgery - American Volume, 13*(4), 535-539.

Reid, D. A., & Price, A. H. (1984). Digital deformities and dental malocclusion due to finger sucking. *British Journal of Plastic Surgery, 37*(4), 445-452.

Rock, W. P. (1988). In Grundy M. C., Shaw L. (Eds.), *Diagnostic Picture Tests in Paediatric Dentistry*. (pp. 83). Ipswich: Wolfe Medical.

Schneider, P. E., & Peterson, J. (1982). Oral habits: Considerations in management. *Pediatric clinics of North America, 29*(3), 523-546.

Shawker, T. H., Sonies, B., Hall, T. E., & Baum, B. F. (1984). Ultrasound analysis of tongue, hyoid, and larynx activity during swallowing. *Investigative Radiology, 19*(2), 82-86.

Shawker, T. H., Sonies, B., Stone, M., & Baum, B. J. (1983). Real-time ultrasound visualization of tongue movement during swallowing. *Journal of Clinical Ultrasound, 11*(9), 485-490.

Shawker, T. H., & Sonies, B. C. (1984). Tongue movement during speech: A real-time ultrasound evaluation. *Journal of Clinical Ultrasound: JCU, 12*(3), 125-133.

Shroeder, C., Gordon, B., & Hawk, B. (1983). In Roberts M. C., Walker C. E. (Eds.), *Handbook of Clinical Child Psychology*. (pp. 295-334). New York: J. Wiley.

Smith, A. (1992). The control of orofacial movements in speech. *Critical Reviews in Oral Biology and Medicine, 3*(3), 233-267.

Smith, G. A. (1996). Treatment of an adult with a severe anterior open bite and mutilated malocclusion without orthognathic surgery. *American Journal of Orthodontics and Dentofacial Orthopedics, 110*(6), 682-687.

Sparling, J. W., Van Tol, J., & Chescheir, N. C. (1999). Fetal and neonatal hand movement. *Physical Therapy, 79*(1), 24-39.

Srinivasan, J., Hutchinson, J. W., & Burke, F. D. (2001). Finger sucking digital deformities. *Journal of Hand Surgery - British Volume, 26*(6), 584-588.

Stone, M., & Shawker, T. H. (1986). An ultrasound examination of tongue movement during swallowing. *Dysphagia, 1*(2), 78-83.

Stone, M., Shawker, T. H., Talbot, T. L., & Rich, A. H. (1988). Cross-sectional tongue shape during the production of vowels. *Journal of the Acoustical Society of America, 83*(4), 1586-1596.

Straub, W. J. (1960). Malfunction of the tongue: Part I. the abnormal swallowing habit: Its cause, effects, and results in relation to orthodontic treatment and speech therapy. *American Journal of Orthodontics, 46*(6), 404-424.

Subtelny, J. D. (1970). Malocclusions, orthodontic corrections and orofacial muscle adaptation. *Angle Orthodontist,* (3), 170-201.

Subtelny, J. D., & Subtelny, J. D. (1973). Oral habits--studies in form, function, and therapy. *Angle Orthodontist, 43*(4), 349-383.

Svedmyr, B. (1979). Dummy sucking. A study of its prevalence, duration and malocclusion consequences. *Swedish Dental Journal, 3*(6), 205-210.

Takada, K., Sakuda, M., Yoshida, K., & Kawamura, Y. (1980). Relations between tongue volume and capacity of the oral cavity proper. *Journal of Dental Research, 59*(12), 2026-2031.

Teanech, N. J., & Fogel, B. (1974). Therapy can curb tongue-thrust swallowing. *Journal of the American Dental Association, 89*(5), 1038.

Traisman, A. S., & Traisman, H. S. (1958). Thumb- and finger-sucking: A study of 2,650 infants and children. *The Journal of Pediatrics, 52*(5), 566-572.

Tulley, W. J. (1969). A critical appraisal of tongue-thrusting. *American Journal of Orthodontics, 55*(6), 640-650.

Turner, S., Nattrass, C., & Sandy, J. R. (1997). The role of soft tissues in the aetiology of malocclusion. *Dental Update, 24*(5), 209-214.

Usumez, S., Uysal, T., Sari, Z., Basciftci, F. A., Karaman, A. I., & Guray, E. (2004). The effects of early preorthodontic trainer treatment on class II, division 1 patients. *Angle Orthodontist, 74*(5), 605-609.

Vanderas, A. P., Voila, P., & Papagiannoulis, L. (2001). Urinary catecholamines as a measure of emotional stress in children with a digit-sucking habit: A preliminary study. *Journal of Dentistry for Children, 68*(3), 179-182.

Vazquez-Nava, F., Quezada-Castillo, J. A., Oviedo-Trevino, S., Saldivar-Gonzalez, A. H., Sanchez-Nuncio, H. R., Beltran-Guzman, F. J., et al. (2006). Association between allergic rhinitis, bottle feeding, non-nutritive sucking habits, and malocclusion in the primary dentition. *Archives of Disease in Childhood, 91*(10), 836-840.

Vig, P. S., & Cohen, A. M. (1974). The size of the tongue and the intermaxillary space. *Angle Orthodontist, 44*(1), 25-28.

Villa, N. L., & Cisneros, G. J. (1997). Changes in the dentition secondary to palatal crib therapy in digit-suckers: A preliminary study. *Pediatric Dentistry, 19*(5), 323-326.

Wallen, T. R. (1974). Vertically directed forces and malocclusion: A new approach. *Journal of Dental Research, 53*(5), 1015-1022.

Warren, J. J., Slayton, R. L., Bishara, S. E., Levy, S. M., Yonezu, T., & Kanellis, M. J. (2005). Effects of nonnutritive sucking habits on occlusal characteristics in the mixed dentition. *Pediatric Dentistry, 27*(6), 445-450.

Watson, T. S., Meeks, C., Dufrene, B., & Lindsay, C. (2002). Sibling thumb sucking: Effects of treatment for targeted and untargeted siblings. *Behavior Modification, 26*(3), 412-423.

8. Appendices

8.1. Appendix I: Consent Form

Faculty of Dentistry

University of Toronto

RESEARCH CONSENT FORM

Clinical trial: a prospective clinical trial to compare the effects of two habit breaking appliances; conventional Bluegrass appliance and Myofunctional Trainer appliance in children with open bite due to an oral habit.

Investigator:
Dr Ihab Suwwan, Dentist and Paediatric Dentistry Graduate Student, University of Toronto Tel: (416) 979-4750 ext. 3029

Purpose:
Compare treatment of two habit breaking appliances; conventional Bluegrass appliance and Myofunctional Trainer appliance in children with oral habits such as: finger sucking habits, tongue thrusting. The aim of these intraoral appliances is to break oral habits with their negative effects in the developing occlusion, and facial aesthetics.

Description:
The Bluegrass appliance has been shown as an effective treatment for oral habits, which has been described as a potential factor in the development of malocclusion and relapse of orthodontic treatment. While the Myofunctional Trainer is a new modality of treatment for habit breaking and it is a removable appliance which is recently being investigated, at least one clinical trial have shown that favorable tooth position could be achieved. However it is important to establish whether the Myofunctional Trainer appliance can stop oral habits as claimed by the manufacturing company.
For each participant; impressions, standard full dental radiographic series (e.g., panorex, lateral cephalogram), photographs, ultrasonographic records, and speech record will be taken before the beginning, during (whenever necessary), and after the end of treatment.
Your child will receive either the Bluegrass appliance or the Myofunctional Trainer appliance; this is dependent on his case and the requirement of the study.

Potential Harms Injuries, Discomforts or Inconvenience:
Because the Myofunctional Trainer is a removable appliance, patient cooperation and compliance with the given instructions is of utmost importance in achieving the desired results, however lack of compliance will lead to delay, and possible adverse effects on teeth occlusion. It is also important to understand that this treatment is considered as a first phase of the

comprehensive orthodontic treatment, which might be followed by a second phase to achieve the desired goal. The Myofunctional appliance is made of silicon or polyurethane material, which is similar to the mouth guard appliance placed in the mouth during contact sport activities.
In case of Bluegrass appliance, patient discomfort with speech is anticipated in the first few days of treatment.

Potential Benefits:
Because of its nature as a removable appliance the Myofunctional Trainer can be removed from the mouth during eating, school time, and different social activities. When it is placed inside the mouth, it might help your child to learn how to breathe from their nose. In children undergoing speech language training they can continue their speech training without the interference caused by these habit-breaking appliances.

Alternatives:
Alternatives include no treatment provided with its deleterious effect on teeth occlusion and aesthetic. Other alternative include punitive appliances such as palatal crib, lingual spurs.

Confidentiality:
Confidentiality will be respected and no information that discloses the identity of your child will be released or published without consent unless required by law. For your information, the research consent form will be inserted in the patient health record.

Participation:
Participation in research is voluntary. If you choose not to participate, you and your family will continue to have access to quality care at the University of Toronto, Faculty of Dentistry. If you choose on behalf of your child to participate in this study you can withdraw your child from the study at any time. Again, you and your family will continue to have access to quality care at the faculty.

Consent:
I acknowledge that the research procedures described above have been explained to me and that any questions that I have asked have been answered to my satisfaction. I have been informed of the alternatives to participation in this study, including the right not to participate and the right to withdraw without compromising the quality of dental care at The University of Toronto Faculty of Dentistry for my child and for other members of my family. As well, the potential harms and discomforts have been explained to me and I also understand the benefits (if any) of participating in the research study. I know that I may ask now, or in the future, any questions I have about the study or the research procedures. I have been assured that records relating to my child and my child's care will be kept confidential and that no information will be released or printed that would disclose personal identity without my permission unless required by law.

I hereby consent for my child________________________________ to participate in the study.

____
Name of Parent

____
Signature of Parent

____
Name of person who obtained consent

____
Signature Date

8.2. Appendix II: Approval for Scientific Merit

Faculty of Dentistry

University of Toronto

Dr. J. Paul Santerre
Associate Dean (Research)
Phone: (416) 979-4903 x4341
Email: paul.santerre@utoronto.ca

Ref. #04/05-22

May 23, 2006.

Dr. G. Kulkarni
Faculty of Dentistry
University of Toronto

Dear Gajanan,

I wish to inform you that your reply to comments on your application entitled "Comparison of the effect on oral musculature, speech and cephalometric changes, of two treatments for malocclusions resulting from oral habits in children" was assessed by two members of the Research Committee is now approved for scientific merit.

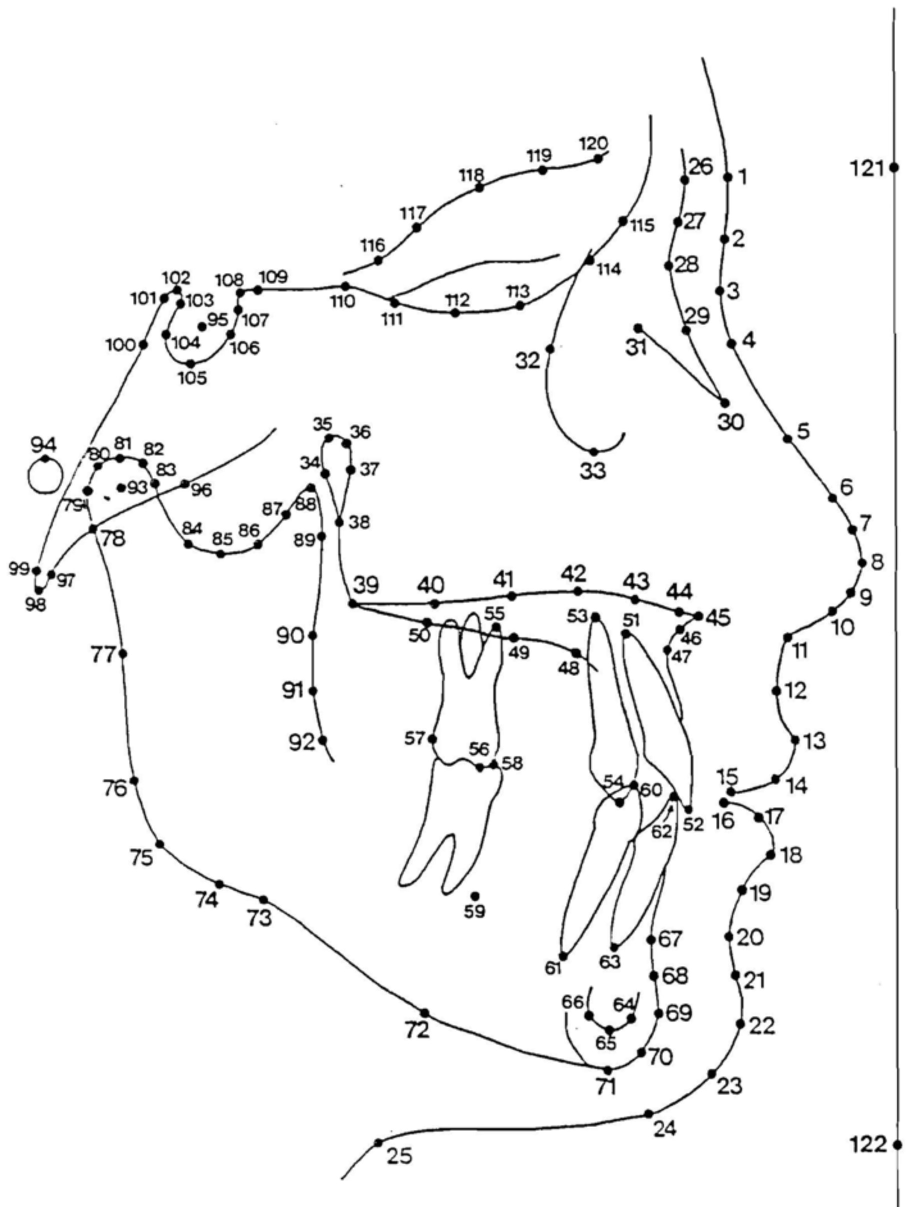
I wish you all the best in this study and I am looking forward to seeing the results at the Faculty's Annual Research Day.

Sincerely,

Leah Raz for
J. Paul Santerre
Associate Dean (Research)

124 Edward Street Toronto Ontario M5G 1G6 FAX (416) 979-4936

8.3. Appendix III: Digitizing Regimen



8.4. Appendix IV: Lateral Cephalometric Landmarks (Dentofacial Planner Software program manual)

Appendix C: Lateral Landmark Library

The Lateral Landmark Library is a library of landmarks which are incorporated into definitions of measurements, reference markers (graphics elements of tracings), and digitizing regimens. Dentofacial Planner's six pre-defined lateral digitizing regimens are built with various combinations of these landmarks.

Each landmark has a corresponding number. The first 122 landmarks in the library are pre-defined digitized landmarks; landmarks which can be incorporated into digitizing regimens. The Aesthetic Lateral regimen is comprised of 122 landmarks in precisely the following sequence, and its pictorial representation in Appendix A can be used to augment the following landmark descriptions. Alternative digitizing regimens incorporate fewer landmarks in varying sequences.

Soft Tissue Profile

1. **Glabella**, the most anterior point on the forehead, in the region of the supra-orbital ridges.
2. A landmark located halfway between Glabella and soft tissue Nasion.
3. **Soft Tissue Nasion**, the deepest point in the soft tissue concavity overlying the naso-frontal suture.
4. A landmark located at the junction of the inferior limit of the concavity of soft tissue Nasion and the dorsum of the nose.
5. **Nasal Dorsum**, a landmark located approximately halfway from Nasion to Pronasale
6. A landmark located at the junction of the dorsum and tip of the nose.
7. **Superior Nasal Tip**, a superior point on the nasal tip.
8. **Pronasale**, the most anterior point on the nasal tip.
9. **Inferior Nasal Tip**, an inferior point on the nasal tip, as the tip becomes confluent with the columella.
10. **Columella**, a landmark on the inferior surface of the nose, representing the anterior delimiter of the naso-labial angle.
11. **Subnasale**, the junction of the columella of the nose with the philtrum of the upper lip.
12. **Superior Labial Sulcus**, the deepest point in the concavity of the upper lip, midway between Subnasale and Labrale Superius.
13. **Labrale Superius**, the muco-cutaneous junction of the upper lip and philtrum.
14. A landmark on the upper lip located midway between Labrale Superius and Stomion Superius.
15. **Stomion Superius**, the most inferior point on the vermilion of the upper lip.
16. **Stomion Inferius**, the most superior point on the vermilion of the lower lip.
17. A landmark on the lower lip located midway between Stomion Inferius and Labrale Inferius.
18. **Labrale Inferius**, the muco-cutaneous border of the lower lip.
19. A landmark located midway between Labrale Inferius and Labiomental Fold.
20. **Labiomental Fold**, the deepest point in the concavity between Labrale Inferius and the soft tissue chin.
21. A landmark located midway between Labiomental Fold and soft tissue Pogonion.

22. **Soft Tissue Pogonion**, the most anterior point on the soft tissue chin.
23. **Soft Tissue Gnathion**, the most antero-inferior point on the soft tissue chin.
24. **Soft Tissue Menton**, the most inferior point on the soft tissue chin, in the region inferior to menton.
25. **Cervical Point**, the junction of the submental region and the neck.

Naso-Frontal Region

26. Frontal 1, the most anterior point on the frontal bone, in the region of the supra-orbital ridges.
27. Frontal 2, a landmark located halfway between Frontal 1 and Nasion.
28. **Nasion**, junction of the frontal and nasal bones at the naso-frontal suture.
29. Nasal 1, a point halfway from Nasion to the tip of the nasal bone.
30. Nasal 2, the tip of the nasal bone.
31. Nasal 3, a point located on the superior aspect of the inferior border of the nasal bone.

Orbit

The orbital landmarks are used to construct an orbital template. These landmarks should be digitized with adequate vertical separation to ensure that the template is not vertically compressed.

32. Orbital Rim, the mid-point (supero-inferiorly) of the lateral orbital margin.
33. **Orbitale**, the most inferior point on the infra-orbital margin (mid-planed).

Pterygo-Maxillary Fissure

34. PTM 1, a landmark at the seven o'clock position of the mid-planed contour of the pterygo-maxillary fissure.
35. Pterygo-Maxillary Fissure, at the eleven o'clock position of the mid-planed contour of the pterygo-maxillary fissure.
36. PTM 3, a landmark at the one o'clock position of the mid-planed contour of the pterygo-maxillary fissure.
37. PTM 4, a landmark at the four o'clock position of the mid-planed contour of the pterygo-maxillary fissure.
38. PTM 5, a landmark at the six o'clock position of the mid-planed contour of the pterygo-maxillary fissure, at the junction of the pterygoid plates and the maxilla.

Maxilla

Most of the maxillary landmarks are used to artistically improve the maxillary contour. Superior Maxilla 5 can be used as the superior landmark for Harvold's Lower Face Height measurement, if digitized at a location representing a 3 mm vertical thickness of ANS. Similarly, the Sub-ANS landmark can represent the anterior delimiter of Harvold's Maxillary Unit Length measurement.

39. **Posterior Nasal Spine**, the posterior limit of the floor of the nose, at the tip of the posterior nasal spine.
40. Superior Maxilla 1, a landmark on the superior surface of the maxilla near PNS.
41. Superior Maxilla 2, another landmark on the superior surface of the maxilla.

42. Superior Maxilla 3, yet another landmark on the superior surface of the maxilla, delimiting posterior and anterior maxillary segments in segmental maxillary osteotomy simulations.
43. Superior Maxilla 4, another landmark on the superior surface of the maxilla.
44. Superior Maxilla 5, a landmark on the superior surface of the maxilla near ANS, at a point where its supero-inferior thickness is 3 mm.
45. **Anterior Nasal Spine**, the anterior limit of the floor of the nose, at the tip of the anterior nasal spine.
46. **Sub-ANS**, a point located on the anterior surface of the maxilla near ANS, at a point where its supero-inferior thickness is 3 mm.
47. **A Point (subspinale)**, the deepest point in the concavity of the anterior maxilla between the anterior nasal spine and the alveolar crest.
48. Inferior Maxilla 1, a landmark on the inferior surface of the maxilla, delimiting posterior and anterior maxillary segments in segmental maxillary osteotomy simulations.
49. Inferior Maxilla 2, another landmark on the inferior surface of the maxilla.
50. Inferior Maxilla 3, yet another landmark on the inferior surface of the maxilla near PNS.

Dentition

The apex and tip landmarks are used to construct tooth templates. The templates are scaled to the distance between apex and tip landmark locations so be sure to digitize these with adequate separation.

51. Upper Incisor Apex, the root apex of the upper central incisor.
52. Upper Incisor Tip, the tip of the crown of the upper central incisor.
53. Upper Cuspid Apex, the root apex of the upper cuspid.
54. Upper Cuspid Tip, the tip of the crown of the upper cuspid.
55. Upper Molar Apex, a point located on a perpendicular to the occlusal surface of the upper first molar through the mesial cusp tip.
56. Upper Molar Crown, the tip of the mesial cusp of the upper first molar.
57. Upper Molar Distal, a landmark located at the distal contact of the upper first molar.
58. Lower Molar Crown, the tip of the mesial cusp of the lower first molar.
59. Lower Molar Apex, a point located on a perpendicular to the occlusal surface of the lower first molar through the mesial cusp tip.
60. Lower Cuspid Tip, the tip of the crown of the lower cuspid.
61. Lower Cuspid Apex, the root apex of the lower cuspid.
62. Lower Incisor Tip, the tip of the crown of the lower central incisor.
63. Lower Incisor Apex, the root apex of the lower central incisor.

Mandible

64. Internal Cortex 1, a landmark located at the anterior aspect of the inner cortical plate of the symphysis of the mandible.
65. Internal Cortex 2, a landmark located at the inferior aspect of the inner cortical plate of the symphysis of the mandible.
66. Internal Cortex 3, a landmark located at the posterior aspect of the inner cortical plate of the symphysis of the mandible.

67. **B Point (supramentale)**, the deepest point in the concavity of the anterior mandible between the alveolar crest and Pogonion.
68. Anterior Genioplasty Point, a point on the chin contour between B Point and Pogonion, which represents the anterior limit of a genioplasty osteotomy. This landmark can serve as Protuberance Menti (Ricketts' PM point) if digitized on the anterior chin contour as it changes from concave to convex.
69. **Pogonion**, the most anterior point on the bony chin.
70. **Gnathion**, the most antero-inferior point on the bony chin, located by bisecting mandibular and facial planes.
71. **Menton**, the most inferior point on the bony chin.
72. Posterior Genioplasty Point, a mid-planed point on the lower border of the mandible representing the postero-inferior limit of a genioplasty osteotomy.
73. Antegonial, a mid-planed point on the inferior border of the mandible at the depth of concavity of the antegonial notch. This is the delimiting landmark between proximal and distal mandibular segments in ramal osteotomy simulations.
74. Inferior Gonion, a mid-planed point at a tangent to the inferior border of the mandible near Gonion.
75. **Gonion**, a mid-planed point at the gonial angle of the mandible located by bisecting the posterior and inferior borders of the mandible.
76. Posterior Gonion, a mid-planed point at a tangent to the posterior border of the ramus near Gonion.
77. Posterior Ramus, a mid-planed point on the posterior border of the ramus, approximately halfway between Gonion and Articulare.
78. **Articulare**, a mid-planed point located at the intersection of the posterior border of the ramus with the inferior surface of the cranial base.
79. Condyle 1, a landmark at the nine o'clock position of the mid-planed contour of the mandibular condyle.
80. Condylion, the most postero-superior point of the mid-planed contour of the mandibular condyle.
81. Condyle 3, a landmark at the twelve o'clock position of the mid-planed contour of the mandibular condyle.
82. Condyle 4, a landmark at the two o'clock position of the mid-planed contour of the mandibular condyle.
83. Condyle 5, a landmark at the three o'clock position of the mid-planed contour of the mandibular condyle.
84. Sigmoid 1, a landmark at the postero-superior aspect of the mandibular sigmoid notch.
85. Sigmoid, a landmark at the depth of the concavity of the mandibular sigmoid notch.
86. Sigmoid 3, a landmark at the antero-superior aspect of the mandibular sigmoid notch.
87. Coronoid 1, a posterior landmark on the coronoid process.
88. Coronoid 2, the tip of the mandibular coronoid process.
89. Coronoid 3, an anterior landmark on the coronoid process.
90. Anterior Ramus 1, a landmark at the superior aspect of the anterior border of the ramus of the mandible.
91. Anterior Ramus, a landmark located in the depth of the concavity of the concavity of the anterior border of the ramus of the mandible.
92. Anterior Ramus 3, a landmark at the inferior aspect of the anterior border of the ramus of the mandible.
93. **Centre of Rotation**, a landmark representing the centre of rotation of the mandible,

arguably the center of the head of the condyle.

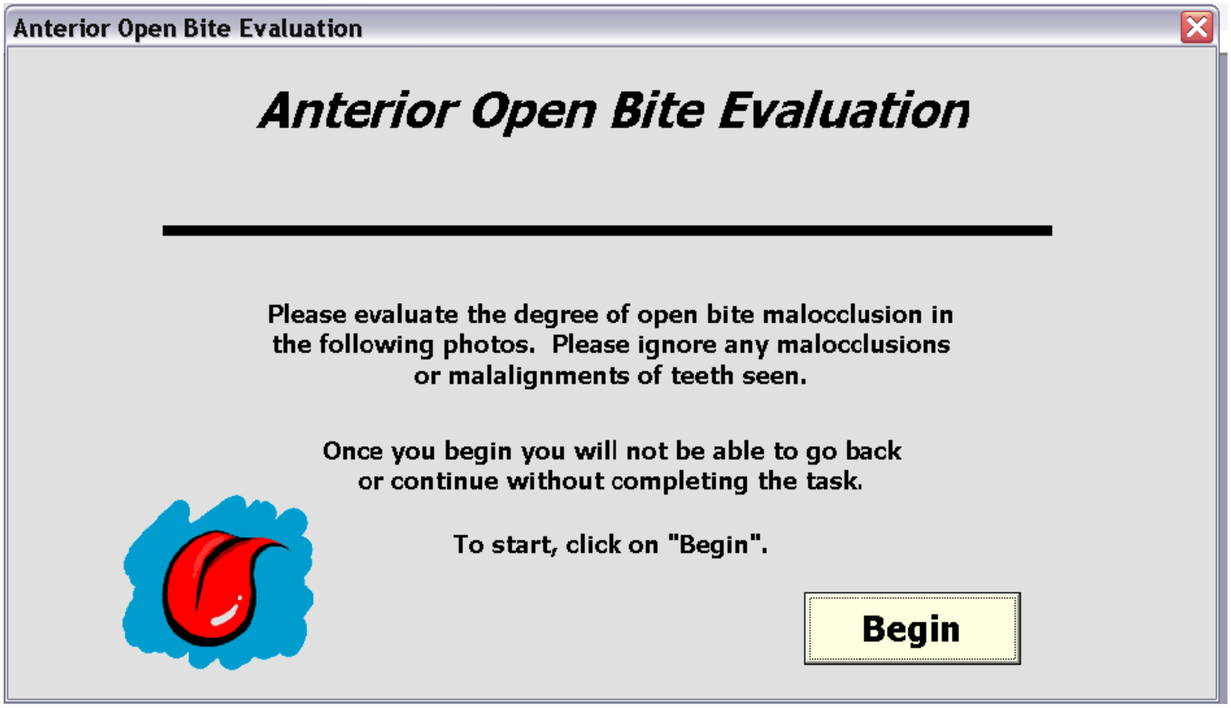
External Auditory Meatus, Cranial Base

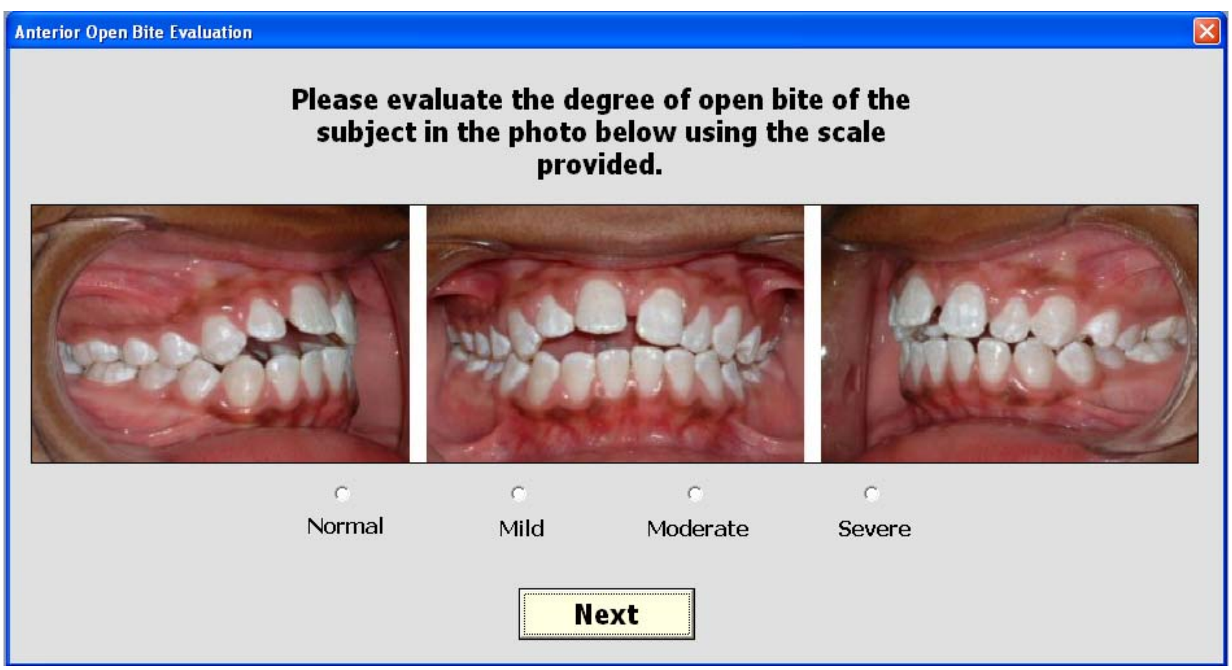
94. **Porion**, the most superior point of the bony external auditory meatus.
95. **Sella**, the midpoint of the sella turcica.
96. SOS, a landmark located on the inferior surface of the basi-occiput in the region of the spheno-occipital synchondrosis.
97. Basion 1, a landmark on the antero-inferior border of the anterior margin of foramen magnum.
98. **Basion**, the most inferior point on the anterior margin of foramen magnum.
99. Basion 3, a landmark on the postero-inferior border of the anterior margin of foramen magnum.
100. Posterior Clinoid 1, a landmark on the posterior contour of the mid-planed posterior clinoid processes.
101. Posterior Clinoid 2, a landmark on the postero-superior contour of the mid-planed posterior clinoid processes.
102. Posterior Clinoid 3, a landmark at the most antero-superior point of the mid-planed posterior clinoid processes.
103. Posterior Clinoid 4, a landmark on the antero-inferior contour of the mid-planed posterior clinoid processes.
104. Sella 1, a landmark at the most posterior aspect of the sella turcica.
105. Sella 2, a landmark at the most inferior aspect of the sella turcica.
106. Sella 3, a landmark at the most anterior aspect of the sella turcica.
107. Tuberculum Sellae 1, a landmark located at the postero-inferior aspect of the tuberculum sellae.
108. Tuberculum Sellae 2, a landmark located at the postero-superior aspect of the tuberculum sellae.
109. Tuberculum Sellae 3, a landmark located at the antero-superior aspect of the tuberculum sellae.
110. Planum Sphenoidale, a landmark at the anterior limit of the planum sphenoidale.
111. Cribriform 1, a landmark on the midline contour of the anterior cranial base approaching the posterior aspect of the cribriform plate.
112. Cribriform 2, a landmark on the midline contour of the anterior cranial base at the inferior aspect of the cribriform plate.
113. Cribriform 3, a landmark on the midline contour of the anterior cranial base at the antero-inferior aspect of the cribriform plate.
114. Cribriform 4, a landmark on the midline contour of the anterior cranial base at the anterior aspect of the cribriform plate.
115. Cribriform 5, a landmark on the midline contour of the anterior cranial base approaching the inner cortex of the frontal bone.
116. Anterior Cranial Base (ACB) 1, a landmark on the contour of the roof of the orbit.
117. ACB 2, another landmark on the contour of the roof of the orbit.
118. ACB 3, another landmark on the contour of the roof of the orbit.
119. ACB 4, yet another landmark on the contour of the roof of the orbit.
120. ACB 5, a final landmark on the contour of the roof of the orbit.

True Vertical Reference Line

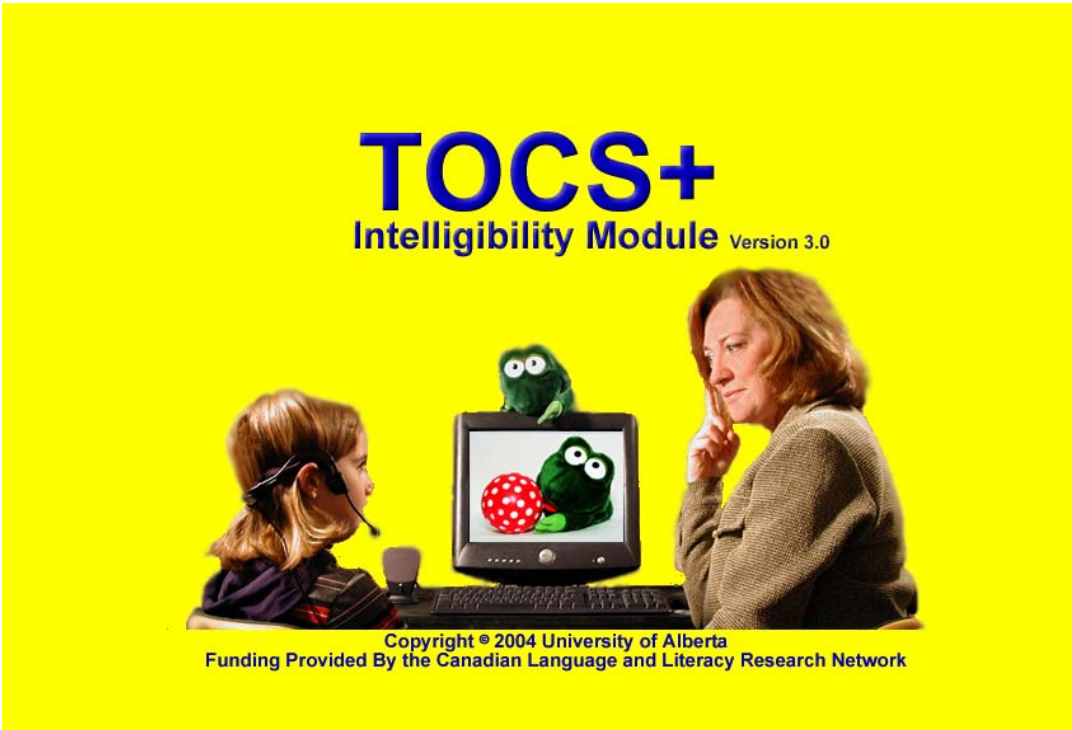
121. **Superior True Vertical**, a point on a true vertical reference line located near the superior limit of the radiographic field.
122. **Inferior True Vertical**, a point on a true vertical reference line located near the inferior limit of the radiographic field.

8.5. Appendix V: Anterior Open Bite Evaluation





8.6. Appendix VI: TOCS+ Program (TOCS+ Program, University of Alberta)



8.7. Appendix VII: Acceptability Spreadsheet and Sound Files

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Sounds	rating	Sounds	rating	Sounds	rating	Sounds	rating	Sounds	rating	Sounds	rating	Sounds	rating	Sounds	rating
2	57	1	58	1	59	3	60	0	61	3	62	2	63	1	64	3
3	65	0	66	1	67	3	68	1	69	1	70	1	71	2	72	3
4	73	1	74	2	75	1	76	1	77	1	78	0				

2	**Bluegrass Appliance**			**Myofunctional Trainer**		
3	MM before appliance 1		He is looking for his car	CE Before appliance 1		A button is missing
4	MM before appliance 2		Pass the woden spoon	CE Before appliance 2		Someone is making a loud noise
5	MM before appliance 3		She has to feed the dog	CE Before appliance 3		He only likes big jelly sandwitches
6	MM immediately after 1		Drain the water from the sink	CE 2 weeks after 1		Send some christmas cards
7	MM immediately after 2		he missed the garbage can	CE 2 weeks after 2		She wants a warm sweater