The Sydney Intrusion Spring (SIS): An appliance for the intrusion of posterior maxillary teeth.

A Prospective Clinical Study

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Dedication

To my beautiful and loving wife Kristelle, for your love, support and encouragement. You have travelled across the world and sacrificed so much in order for me to fulfil my dreams. I am eternally indebted to you. I love you with all my heart, now and forever.

To my mother and father, Elize and Wynand Foot. Thank you for instilling in me the values of hard work, dedication and perseverance. Your love, support and nurturing have made me the man I am today. Thank you for the tremendous sacrifices that you have made over the years, so your children may have a better life. Words will never be enough.

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Continuous effort - not strength or intelligence - is the key to unlocking our potential.

~Sir Winston Churchill~

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Declaration

CANDIDATE CERTIFICATION

This is to certify that the candidate carried out the work in this thesis in the Orthodontic Department at the University of Sydney, and this work has not been submitted to any other university or institution for a higher degree.

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1. Basic facial growth:

1.1 Maxilla:

1.1.1 Embryology

The maxilla initially forms as two maxillary prominences from a centre of mesenchymal condensation in the first pharyngeal arch during the fourth week of development. This area is located on the lateral surface of the nasal capsule, the most anterior part of the chondrocranium. During the fifth week these maxillary prominences enlarge and grow ventrally and medially.[1]

1.1.2 Post-natal Maxillary growth

Growth and development of the maxilla occurs entirely through intra-membranous ossification by two main mechanisms. Firstly, through apposition of bone at the sutures that connects the maxilla to the cranium and cranial base, and secondly through apposition-resorption surface remodelling at the maxillary periosteal membrane.[2]

In the anterior-posterior plane, the overall direction of maxillary growth is downward and forward. During early life this is largely achieved through secondary displacement of the nasomaxillary complex due to expansion of the middle cranial fossa, enlargement of the cerebral lobe and endochondral growth of the cranial base synchondroses. Sagittal lengthening of the maxilla further occurs through appositional growth at the maxillary tuberosities towards the palatine bone. The anterior surface of the maxilla is largely an area of remodelling and resorption mainly associated with the lowering of the nasal floor.[3] Several theories attempt to explain maxillary growth. [4] Scott suggested that appositional growth at the sutures was due to secondary displacement of the maxilla as it was carried downward and forward by growth of the nasal septal cartilage[5]. Others however suggest that sutural growth is due to primary displacement of the maxilla as the soft tissues of the face grow and expand.[6]

Transverse maxillary growth in early postnatal life is partly attributed to rapid lateral growth of the cranial base. This leads to a period of accelerated separation and growth of the intermaxillary; midpalatal and internasal sutures that cause an increase in maxillary width. Several studies[4, 7, 8] have concluded that further growth in width of the maxilla occurs predominantly through growth of the midpalatal suture, along with some appositional growth. Implant studies[3, 9, 10] demonstrated a transverse rotation of the two maxillary halves, which can be explained by the sutural growth being greater posteriorly than anteriorly. On average the transverse growth increase was 6.9mm (5.5-8.2mm) and was completed by the age of seventeen years.[3, 11] In contrast, other authors contend appositional growth along the lateral aspect of the tuberosity and alveolus to be the chief mode of maxillary transverse development, with midpalatal sutural growth only playing a role during prenatal growth and development.[4]

Vertical growth of the maxilla takes place through sutural growth at the maxillary processes, towards the frontal and zygomatic bones; appositional growth on the inferior aspect of the alveolar process, in association with tooth eruption and lastly through apposition-resorption remodelling of the hard palate/nasal floor and the orbits.[9]

The magnitude of this sutural lowering of the maxilla from the age of four years until adulthood was on average 11.2mm with a range from 9.5-13.5mm.[3] The lowering of the floor of the orbit during this time was just under half of that of the maxillary body. Nasal cavity lowering through resorptive remodelling amounted to one third of the total vertical sutural height increase.

Vertical development of the alveolar process and maxillary teeth is of particular clinical significance to orthodontic treatment. Björk and Skieller[3, 11] found the magnitude of vertical alveolar development through appositional growth to be an average of 14.6mm (range 9.5-21mm) between the ages of four to twenty-one years. Furthermore, they found the total increase in height of the alveolar process to be one third less than the total vertical growth of the alveolar process, due to lowering of the nasal floor, through resorption by an average of 4.6mm. The resorption however is greatly varied and is usually larger anteriorly than posteriorly. This vertical development of the alveolar process is accompanied by a continued eruption of the maxillary permanent teeth after their full emergence in the oral cavity. Iseri and Solow[12] found this continued eruption, between the ages of nine to twenty-five years old, to be an average of 6mm downwards, 2.5mm forwards at the incisors and 8mm downwards,3mm forwards at the first molars. In relation to the cranial base this translated, on average, into a translocation of 9.5mm downwards, 6.5mm forwards at the incisors and 12.5mm downwards, 7.5mm forwards at the maxillary first molars. The rate of translocation peaked at 12 years, with 2.5mm/year (eruption: 1.5mm/year) and showed a post-pubertal decrease to the age of seventeen years, where it reached a plateau of 0.1-0.2mm/year.

This clearly demonstrates a vertical growth differential between the anterior and posterior aspects of the face, which has been well described in several longitudinal tantalum implant studies. Vertical rotation of the maxillary complex during growth and development was first described by Björk and Skieller.[13] They described the rotation in terms of either a forward or backward direction. Forward rotation of the maxilla occurs when there is more vertical facial growth posteriorly than anteriorly. For backward rotation this pattern is reversed, relatively greater vertical growth occurring anteriorly compared to posteriorly. This vertical rotation of the maxillary complex is generally less than that seen in the mandible due to the contribution of middle cranial fossa growth. Baumrind *et al.* [7] endeavoured to quantify the magnitude of the rotation and found it to be on average 1.1° "forward". There was however a large inter subject deviation with a standard deviation of 4.6° and a range of 11.3° forward to 6.7° backwards. The rotational changes were also largely complete by the age of thirteen and a half years. The eruption differential found between the incisors and first maxillary molars, by Iseri and Solow[12], also leads to a decrease in the inclination of the upper occlusal plane over time. This differential change in occlusal plane orientation seems to be complete by sixteen years of age, with no further change in the occlusal plane inclination found after this age; thereby indicating parallel eruption of the teeth from this point onwards.

As discussed, growth and development of the maxilla occur differentially in the three planes of space. Transverse growth completes first followed by growth in the anterior-posterior plane. Cessation of growth in the vertical plane is last, largely due to dentoalveolar development.[10]

1.2 Mandible

1.2.1 Embryology

Mandibular growth begins during the fourth week of embryonic development as a condensation of mesenchyme in the first pharyngeal arch just lateral to Meckel's cartilage. Meckel's cartilage itself disintegrates during embryonic development with the remnants persisting as two small bones that form the conductive ossicle within the middle ear and its perichondrium persisting as the sphenomandibular ligament. The condylar cartilage develops initially as an independent secondary cartilage which is separated by a considerable gap from the body of the mandible. During the ninth week of fetal life the condylar cartilage fuses with the developing mandibular ramus.[1]

1.2.2 Post-natal Mandibular growth

Post-natal mandibular growth of the mandible occurs by both endochondral ossification and surface apposition and resorption.[2]

Endochondral ossification occurs at the mandibular condyle at the site of the secondary cartilage. This process is initiated by duplication of the mesenchymal cells in the articular layer of the condyle, followed by their differentiation into chondrocytes and their migration into the cartilage. Chondrogenesis then ensues with hyperplasia and hypertrophy of the chondrocytes, followed by mineralisation, thereby completing the ossification process.

Growth at all other sites of the mandible occurs by surface remodelling via bone apposition and resorption. This has been described qualitatively by Enlow[14] who states that during growth, the mandible is displaced from the glenoid fossa by the growth enlargement of the composite of soft tissues that are developing around it. This downward and forward displacement is then balanced by the upward and backward growth of the condyle to maintain contact with the temporal bone.[14] The principal sites of growth of the mandible include the posterior surface of the ramus and the condylar and coronoid processes, with little change occurring along the anterior part of the mandible. As the body of the mandible grows in length by periosteal apposition of bone on its posterior surface, the ramus grows vertically by endochondral replacement at the condyle, accompanied by surface remodelling. The translation of the mandible is largely due to the soft tissue matrix that allows the bones' downward and forward movement and to a lesser extent a result of the growth of the middle cranial fossa and its articulation with the condyle. This articulation with the glenoid fossa imposes a source of variability as it may in fact create a negative effect on the projection of the chin, as the fossa may move straight down or even posteriorly with growth.[15-17]

Björk and Skieller[17-19] described mandibular growth both qualitatively and quantitatively. Through the use of tantalum pins in longitudinal radiographic studies, they were able to demonstrate that the forward and downward displacement of the mandible also had a component of rotation owing to the pattern of surface remodelling and the direction of condylar growth. Such rotations were described as either forward or backward with sub-types for both.

In general terms, forward rotation of the mandible occurs when there is a decrease in the angle of the mandibular reference lines to the anterior cranial base line. In backward rotation the situation is reversed, with an increase in the angle of the mandibular reference lines to the anterior cranial base line, causing the chin to move in a more backward and downward direction. Forward mandibular growth rotation may be further divided into three sub-types: Type I, where the centre of rotation is located at the temporomandibular joint; Type II, where the centre of rotation is located at the incisal edge of the lower anterior teeth and Type III, where the centre of rotation is displaced distally, often to the level of the premolars. Backward mandibular growth rotations are also subdivide into: Type I, where the centre of rotation is located at the temporomandibular joint and Type II, where the centre of rotation is the distal occluding molars. The growth rotation in the mandible was found to be far greater than in that of the maxilla, leading to an average decrease in the mandibular plane angle of 4.1° (i.e. forward rotation).Condylar growth direction was found to also have significant individual variation, with growth direction not always linear but in fact having a distinct curvature. The gonial angle decreased with vertical condylar growth and increased with sagittal direction of growth. On average the condylar growth direction is 6° forward, relative to tangent on the posterior ramus and a 123° with respect to the lower border of the mandible.[17, 20-22]

In addition, they (Björk and Skieller, 1969) also described these mandibular growth rotations in terms of Matrix rotation, Total rotation and Intramatrix rotation. Matrix rotation is defined as the rotation of the soft tissue matrix of the mandible, relative to the anterior cranial base. The soft tissue matrix is taken to be the tangential mandibular lower border line on a lateral cephalogram. Total rotation is defined as the rotation of the mandibular body relative to the anterior cranial base. The mandibular body change is measured as a change in the inclination of a reference line or implant line in the body of the mandible, relative to the anterior cranial base. Intramatrix rotation is defined as the difference between the Total rotation and the Matrix rotation and is an expression of the remodelling that occurs at the lower border of the mandible. It is measured as the change in inclination of the implant line relative to the mandibular tangential line.

On average, the growth of the mandible continues at a relative steady rate before puberty, showing ramus height increases in the range of 1-2mm per year, and body length increases of 2-3mm per year.[17] Longitudinal studies of craniofacial growth show a large proportion of individuals, especially girls, exhibit a juvenile acceleration in jaw growth which occurs on average one to two years before the adolescent growth spurt.[23] This juvenile acceleration can equal or even exceed the jaw growth that accompanies secondary sexual maturation. In boys, if this juvenile growth spurt occurs, it is usually less intense than the pubertal acceleration of jaw growth. Transverse growth of the mandible completes first and is established largely before the pubertal growth spurt. Sagittal growth of the mandible is the next to cease, followed lastly by growth in the vertical dimension.[23]

2.0 Skeletal Anterior Open Bite malocclusion

2.1 Definition

The term 'skeletal anterior open bite' malocclusion was first coined and subsequently described by Subtelny and Sakuda.[24] They defined this malocclusion to be: "a deviation from the normal in the vertical relationship of the maxillary and mandibular dental arches leading to a definite lack of contact, in the vertical dimension, between the opposing segments of teeth." The degree of lack of contact in the vertical dimension might vary from patient to patient, but must be present to be classified as an open bite. Furthermore, on a lateral cephalometric radiograph, taken with the teeth in occlusion, there must be a definite separation between the upper and lower incisal edges when measured relative to the occlusal plane or at a perpendicular to the palatal plane.

2.2 Prevalence

The reported prevalence of open bite malocclusion in the published literature varies greatly. One study reports the incidence of open bite malocclusion to be 2% among fifteen year old British adolescents.[25] In the United States the NHANES III epidemiological study of 7000 children, between the ages of eight to seventeen, reports the incidence of open bite to be 6.6% among African-Americans, 2.9% among Caucasians and 2.1% among Hispanic-Americans.[26]

2.3 Aetiology

Discussion in the literature on the aetiology of vertical malocclusions, skeletal anterior open bites or the so called 'long face syndrome' is often distinctly seperated into the categories of genetic and environmental causes. This often leads to the so called 'Nature versus Nurture' argument. It must however be remembered that development ultimately stems from a complex interplay between several different aetiological factors during growth. These factors are often intimately related and rarely work in isolation or independently from each other.[27, 28]

Nevertheless, several studies have tried to quantify the relative contribution of genetic versus non-genetic influences in the development of skeletal open bite malocclusion.[29-32] Such relative contribution is expressed as heritability factor. Heritability factor is defined as the proportion of the total phenotypic variance in a sample that is contributed by genetic variance; i.e. a characteristic with a heritability factor of 1 is said to be expressed without any environmental influence, whereas a characteristic with a heritability factor of 0.5 has half its variability (between individuals) influenced by the environment and half by genotypic factors. [33] These studies report heritability factors for upper to lower face height between 0.52-0.71 and posterior face height of 0.88. For the sake of discussion however it is convenient to discuss these aetiological factors in isolation.

2.3.1 Hereditary Factors

There is great diversity in the literature with respect to the component of growth that constitutes the main aetiological factor of skeletal open bite malocclusion.

Mandibular growth and specifically condylar growth direction have been implicated in several studies as a major aetiological factor in the development of a skeletal open bite malocclusion. The authors of these studies were able to demonstrate the growth direction of the condyle in well proportioned individuals to be vertical and somewhat anteriorly directed whereas patients with skeletal anterior open bites had condylar growth that tended to be progressively posterior, leading to a vertical expression of growth at the chin, a dental Class I or II malocclusion and an anterior open bite.[3, 9, 10, 13, 17-19]

Aetiological factors pertaining to growth are however not only confined to the direction of condylar growth. The landmark growth studies by Björk and Björk & Skieller[3, 9, 10, 13, 17, 19, 22] explain how growth rotations due to surface remodelling may contribute to skeletal anterior open bite. These studies clearly demonstrate that periosteal surface remodelling in both jaws during growth lead to both internal and total rotation of the jaws as development proceeds. The majority of the study population exhibited a forward pattern of mandibular rotation, contrasting to the backward rotation observed in the subjects with skeletal anterior open bite. This rotation is largely due to a discrepancy in the developmental increments of anterior versus posterior face height. Several studies suggest that excessive posterior maxillary dentoalveolar development is the principal factor behind backward rotation of the mandible during growth[24, 34-41]; however other studies do not draw the same conclusion.[42-44]

Underdevelopment in middle cranial fossa height and an increased cranial base angle have also been documented in the literature as aetiological factors behind skeletal anterior open bite malocclusion.[45, 46] These two factors exert their aetiological role by reducing the extent of lowering of the mandibular condyle during growth.

Björk and Skieller[3, 13] further suggest that inadequate alveolar growth in the anterior portion of the maxilla to be responsible for open bite development. However several subsequent studies have found the opposite to be true.[34, 35, 41] These studies maintain that there is an excessive development of both the anterior and posterior maxillary dentoalveolar height in skeletal anterior open bite patients and argue that inadequate anterior dentoalveolar development is an infrequent finding in these subjects.

Research has found 'long face' adults to have significantly weaker masticatory muscles which produce greatly reduced occlusal force during swallowing, chewing and maximum biting when compared to 'normal face' adults.[47] It has therefore been postulated that the weaker musculature will lead to the development and maintenance of a skeletal anterior open bite malocclusion.[48-50] This theory has however been refuted by evidence that suggest that there is no difference in the occlusal forces produced by 'long face' and 'normal face' children.[51] Weak masticatory muscles are therefore the result of the high angle, anterior skeletal open bite malocclusions and not the cause.[52, 53]

2.3.2 Environmental Factors

The role of environmental factors involved in the development of skeletal anterior open bite malocclusion has been studied extensively and is controversial in the orthodontic literature. Environmental factors postulated to play a role in the aetiology of skeletal anterior open bites are difficult to examine in isolation from hereditary and other confounding factors. Hence, proving a link between these factors and skeletal anterior open bites has been arduous.

Respiratory pattern, and more specifically the role of oral respiration as an environmental factor in malocclusion, has been the subject of debate for more than a century. Several studies have shown a strong link between airway problems such as large adenoids, tonsils or nasal obstruction caused by septum deviation, large conchae or allergies.[54-58] These findings in conjunction with the characteristic 'long face' appearance, common in many patients with anterior open bite malocclusion have led to the description of 'adenoid faces'. The authors of these studies postulate that the abovementioned conditions lead to oral respiration, which in turn leads to an alteration of the growth pattern, and the development of a skeletal anterior open bite. However, opponents of such claims are critical of the research methodology used in these studies. In addition, they cite the fact that the majority of patients with skeletal anterior open malocclusion have no evidence of nasal obstruction. This does not support the notion that airway problems lead to skeletal anterior open bite malocclusions.[59-61] Therefore, it can be concluded that although oral respiration may contribute to the development of skeletal anterior open bite malocclusion, it is unlikely that it can be implicated as a frequent, sole aetiological factor.

Swallowing pattern and tongue posture are other environmental factors that have been implicated in the development of a skeletal anterior open bite malocclusion. Early authors believed tongue thrust swallow to be the direct result of improper bottle feeding and that this would lead to the development of an anterior open bite.[62-65] This has since been disproved and contemporary thinking in line with the Equilibrium Theory suggests that an anterior tongue thrust swallowing pattern simply does not apply a force for a sufficient period of time to affect tooth movement. Rather, the swallowing pattern is an adaption in individuals with an anterior open bite malocclusion to achieve an anterior oral seal during swallowing.[2, 66, 67]

Moyers described two types of abnormal tongue posture: the acquired protruded tongue posture associated with tonsillitis and chronic pharyngitis, which has a positive prognosis and the endogenous protracted tongue posture, which has a poor prognosis. The presence of this protracted tongue position has been verified to be present in individuals with skeletal anterior open bite malocclusion.[68] It has been postulated that this relates to airway maintenance, based on the notion that increased genioglossus muscle activity may be involved in expanding the pharyngeal diameter leading to a more patent airway from the larynx to the nose.[69, 70] Despite the controversy surrounding the role of respiratory pattern in the development of skeletal anterior open bite malocclusion, there is consensus in the orthodontic literature that this protracted tongue position, in the least, exerts enough force for a sufficient period to affect tooth movement and cause a dental anterior open bite.[71]

2.4 Clinical features

From everyday life it is evident that the expression of the human facial form is almost infinite. As clinicians it can be appreciated that even subtle change in facial form can lead to dramatic differences in facial characteristics and that these subtle nuances in part define each person as an individual. Therefore, it is not surprising that the intra-oral and extra-oral features can be highly variable in different subjects with skeletal open bites. Authors have described a wide range of clinical features and cephalometric traits descriptive of skeletal anterior open bite that are common to *most* individuals. However, in any given individual with this type of skeletal dysplasia, several or only a few of the reported characteristics may be observed.

In general, skeletal anterior open bite individuals present with narrow faces that are long and ovoid in appearance and may often have a convex profile, but straight or concave profiles also occur infrequently. The upper third of the face is within normal limits in terms of length, but the temporal fossae may appear to be small. The middle third of the face shows a slender narrow nose, alar base and nasal apertures with a depressed nasiolabial area. In profile the middle third is often characterised by a prominent nasal dorsum and recessed nasiolabial area, although the nasiolabial angle appears normal. The lower facial third sees an overtly increased facial height, increased tooth display at rest and excessive tooth and gingival display during animation or on smiling, due to inadequate upper lip length (although the lip length is normal in terms of population norms). The lips are incompetent at rest with a large interlabial gap and a conscious effort to bring the lips together produces characteristic circum-oral muscle strain. On swallowing there is active contraction of the oro-facial musculature including severe mentalis muscle participation. In profile the lower third often displays the impression of an underdeveloped mandible which leads to a retrognathic chin appearance and lack of mental protuberance. There is marked antegonial notching and a steep angle to the lower border of the mandible. The masticatory muscles appear curved and the masseter muscle attachments are located posterior to the posterior teeth.[53]

Intra-orally the palatal vault appears high and narrow and an extensive anterior open bite, which may extend as far as the molars, is often present. This open bite generally tends to be symmetrical. It has been suggested that dentally, the teeth are proportionally large leading to crowding or bidental proclination. The crowding has been attributed, by some, to the active pressure exerted by the lips and circum-oral musculature. Evidence also exists as to a small cuspal height on the posterior teeth, large molar height, frequent impaction of the third molars and a reduced freeway space.[45, 46] The tongue may be habitually postured forward and a simple tongue thrust exists to accomplish an anterior oral seal during swallowing. The gingival condition may also hypertrophic and desiccated due to continuous air exposure.

2.5 Cephalometric features

Much controversy, conflict and contradiction exist regarding several key cephalometric features associated with skeletal anterior open bite malocclusion. This might be attributed to difference in sample population age, ethnic background, inclusion criteria and definition or 'stable' landmarks chosen for superimposition.

An increase in anterior face height, mainly due to an increase in lower anterior face height, is the most commonly cited feature associated with skeletal open bite malocclusion. In general, the upper face height seems to be unaffected or somewhat reduced. This relationship leads to a reduced ratio of UFH/LFH. The posterior face height has also been found to be reduced in several studies and this in combination with the increased anterior face height leads to a reduction of the PFH/AFH ratio.

The majority of literature has found no difference in the cranial base relationship of skeletal open bite individuals compared to normal individuals, suggesting that the dysplasia arises below the level of the cranial base. Some however have described the cranial base as sometimes being dolicephalic in nature with a more obtuse cranial base angle, leading to more superiorly positioned condylar fossae in individuals with skeletal open bite problems.[45, 46, 72] Subtelny[24] however argues the cranial base angle to be more acute, the distance between Sella and Basion to be reduced and the maxillary alveolar processes to be more distally positioned in cases with skeletal open bites.

Several authors suggest: an inferiorly positioned maxillary process; maxillary posterior vertical excess with concomitant posterior inferiorly tipped palatal plane; and an increased posterior and anterior maxillary dento-alveolar height, to be major and frequent characteristics of a skeletal open bite malocclusion.[24, 28, 34-36, 40, 41, 45, 46, 52, 72] This is thought to be due to excessive vertical maxillary development. Solow[73] believes that it is compensatory or dysplastic adaption to these changes that determine the over bite, or lack thereof in individuals with skeletal open bite problems. However some authors question these findings and propose the posterior maxillary dento-alveolar height to be normal, the anterior dento-alveolar height to be reduced and the palatal plane to be tipped upwards anteriorly.[42-44]

In the mandible an increased mandibular plane angle, large gonial angle with antegonial notching, short ramal height, backward and downward mandibular growth rotation and an increased mandibular to palatal plane angle are common features seen in skeletal open bite dysplasia. Generally the mandibular symphysis tends to be long in height, but narrow antero-posteriorly. Controversy exists as to whether the molar dento-alveolar height is increased, decreased or normal. Disagreement also persists as to the proportional size of the different mandibular components; with some arguing these to be normal and while others suggest that they are small, causing a retrognatic mandibular appearance.

Schudy[36] first suggested the concept of facial divergence and hyperdivergence as the extreme seen in skeletal open bite dysplasia. Sassouni[45, 46] agreed and showed the four facial planes (optic, palatal, occlusal and mandibular) are highly divergent and intersect close to the face in these individuals. Furthermore, it has been shown that the palatal plane and occlusal plane are increased relative to Sella-nasion and that two distinct occlusal planes exist (maxillary, which is tipped up and mandibular, which is tipped down).[42, 43]

2.6 Neuromuscular features

Studies have shown that patients with skeletal open bite dysplasia have weaker masticatory muscles as an effect of the increased vertical dimensions.[47-50, 53] The masseter and temporal muscles have been shown to be hypotrophic. Some subjects have revealed a lack of 'gag reflex'. Stereognotic test of these individuals discovered that they are unable to execute alternate repetitive movements with the tongue (dysdiadokokinesis) and cannot identify different shaped objects with their tongue.[42]

2.7 Features of associated malocclusion

Although skeletal anterior open bite dysplasia may be associated with Class I, Class II or Class III dental malocclusion, Class II tends to be the most common finding. This is due to the retrognathic position of the mandible and/or the backward and downward rotation of the mandible. Bidental proclination or an increased overjet may also be associated with this malocclusion.

Bilateral posterior crossbite or tending posterior crossbite is a frequent observation and studies have shown that there is often a concomitant transverse dysplasia associated with skeletal open bite problems. This discrepancy is due to a narrow transverse skeletal maxillary width and a wide transverse dental mandibular width.[74, 75]

Dental crowding is another frequently related problem in these individuals. This may be due to having proportionally large teeth[45] or the effect of the circum-oral musculature causing pressure on the incisor teeth, leading to flattening and crowding of the arches.[35]

The degree of open bite or over bite present in these individuals with skeletal open bite malocclusion has been attributed to the extent of the dentoalveolar compensatory or dysplastic adaption to underlying skeletal problems.[73] Therefore, although various amounts of dental open bite might generally be present in these cases, it is possible for an individual to present with several of the distinguishing features of skeletal open bite, without having an anterior dental open bite.[76]

2.8 Differences between Skeletal and Dental Open bite malocclusion

As a rule, individuals with skeletal anterior open bite dysplasia will display characteristics of both skeletal and dental open bite as the underlying skeletal pattern influences the position and morphology of the dentition. However, individuals with a purely dental anterior open bite malocclusion have no underlying skeletal dysplasia and will therefore show no characteristic extra-oral features.

Intra-orally the shape of the dental arches and position of the dentition will reflect the underlying aetiology of the dental anterior open bite. Examples include; localised infra eruption of certain teeth, proclined incisors and a V-shaped arch, lower incisors that are depressed and lingually inclined, anterior open bite limited to the incisors and a characteristic 'fish mouth' appearance in occlusion. As with skeletal open bite dysplasia these individuals often exhibit a tongue thrust swallow in order to achieve an anterior oral seal during swallowing.[24, 25, 28, 43, 65, 77]

In cephalometric terms dental open bite individuals generally have no defining skeletal features, but an increased incidence of skeletal II relationships have been reported in subjects with a thumb sucking habit. This is thought to be due to the mechanical action of the thumb, encouraging forward displacement of the maxilla. Dental open bite individuals may exhibit a decreased incisal height to the palatal plane and maxillary occlusal plane that is tipped up anteriorly, but no increase in posterior dentoalveolar height as seen in skeletal open bite individuals. The mandibular plane, gonial angel and mandibular occlusal plane all exhibit a normal inclination. The lower incisors may appear retroclined, but the dentoalveolar height is normal.[25, 37, 77]

3.0 Conventional methods of Open bite Treatment

3.1 Extra-oral appliances

3.1.1 Headgear:

The use of extra-oral force was first described by Cellair in the early 1800's. It was repopularised by Kloehn in the 1940's after it had fallen into disuse. He later improved his design through the invention of the facebow.

Vertical orthopaedic changes to the nasomaxillary complex and/or control of the maxillary dentition using headgear in skeletal open bite individuals, is most often achieved through the use of high-pull or combination pull headgear.

Several animal studies have demonstrated the ability of high-pull headgear, not only to influence the upward and distal displacement of the maxillary teeth, but also the growth and remodelling of the maxillary sutures. They suggested that the extra-oral traction restrained and/or reversed the normal maxillary downward and forward sutural growth, allowing subsequent forward autorotation of the mandible. The effects appear to be 50% dental and 50% skeletal in nature. Results advocate moderately heavy forces (600-700g per side) and the direction of pull to be of critical importance in the type of changes achieved.[78, 79]

Human studies on the other hand have not been as consistent in their findings. Some suggest molar bands and a transpalatal arch to be a sufficient application appliance, whilst others insist on the use of a maxillary splint appliance that partially or fully covers the dentition to achieve an orthopaedic effect. Force magnitude also varied greatly with suggestions ranging anywhere from 300-1500g of force. Most however use forces in the range of 400-600g. Direction of force application ranged between 20-60° to the occlusal plane, with most agreeing on 30-40° in accordance with the findings of Poulton.[80] Position of the outer bow varied anywhere from between the lateral incisor/canine region to distal to the molars. The popular consensus being somewhere either side of the second premolar. Daily application times range from 10-24 hours per day with several authors agreeing the magnitude of the treatment effect to be largely dependent on the number of hours per day rather than the total months of treatment time. Total treatment time with headgear ranged between 4.5-36 months. Authors further suggest that shorter treatment times appear to achieve mostly orthodontic effects, whilst longer treatment times produce greater orthopaedic effects. The treatment outcomes varied from purely dental, with intrusion or no extrusion of the maxillary molars, lingual tipping and extrusion of incisors and concomitant extrusion of the mandibular molars to highly significant vertical orthopaedic restraint of the maxillary position, maxillary posterior dental intrusion, no concomitant extrusion of the mandibular molars and forward autorotation of the mandible.[81-93]

Recently a new appliance has been described in the literature, consisting of a modified full coverage acrylic cap splint expander used in conjunction with a newly designed facebow and occipital headgear to cause intrusion of the maxillary posterior teeth and a clockwise moment on the maxillary dento-alveolar complex. The modified full coverage acrylic cap splint expander with tubes between the maxillary first and second premolar on either side, for insertion of a facebow, was used in conjunction with a newly designed facebow and occipital headgear. The outer bows of the facebow were bent downward at an angle of 45° and ended at the centre of resistance of the maxillary dentoalveolus, sagittally and vertically, 50-60mm below the centre of resistance. After initial expansion the occipital high-pull headgear was placed to deliver a force of 500g per side. Patients wore the appliance 14-16 hours per day for six months. Results were promising, showing a clockwise rotation of the maxillary dentition, reduction in mandibular plane angle, maxillary molar intrusion of 2.81mm and an over bite increase of 3.75mm.[94]

Functional orthopaedic appliance therapy in conjunction with high-pull headgear has also been advocated in the literature to control the vertical dimension during Class II orthopaedic correction in individuals with both vertical and antero-posterior skeletal dysplasia. Teuscher[95] suggested the use of high pull headgear with activator treatment and demonstrated that the dual appliance approach was able to restrict the maxilla vertically while simultaneously 'unlocking' the mandible to achieve greater mandibular prognatism. Recently authors studying the effects of the Herbst appliance combined with high-pull headgear were able to demonstrate that this appliance delivered superior results to that achievable with the headgear/activator appliance. These results were shown to be the effect of restricted maxillary growth, increased mandibular growth and absence of lower facial height increases.[96, 97]

3.1.2 Vertical Pull Chin Cup therapy:

The Vertical pull chin cup has been used as an auxiliary appliance in the functional orthopaedic treatment of skeletal open malocclusions for well over a century. It is thought to cause an anterior rotation of the mandible, thereby closing the open bite, by passing a vertical vector of force through the anterior part of the mandibular body. It may be used alone, with fixed orthodontic appliances or in conjunction with functional appliances.[98]

Pearson[99] suggested that although High pull headgears were effective in controlling the maxillary posterior height in skeletal open bite individuals, it did not address control of the mandibular alveolar height, which was at least as important. He therefore recommended use of the vertical pull chin cup to address control of the mandible during skeletal open bite treatment. The appliance should be worn for at least 12 hours per day, applying a force of a minimum of 450g per side. Results demonstrate a significant decrease in the mandibular plane angle and increase in over bite in nine months of treatment. The author stressed however that this treatment modality should only be used in growing individuals. These results were confirmed in a recent study where the Chin Cup Therapy was used sixteen hours a day for six to twelve months. The investigators applied a force of 400g per side and were able to produce a reduction in open bite by an average of 3.92mm.[98]

This Vertical Pull Chin Cup has also been shown to be effective in controlling the unwanted vertical side effects caused by rapid maxillary expansion (RME). In a study by Basciftci and Karaman the RME with chin cup group showed no significant decrease in over bite during expansion treatment. Compared to a control group of RME only subjects there was a difference in open bite decrease of 2.02mm.[100]

3.2 Functional orthopaedic appliances

3.2.1 Functional Regulator-4 appliance (FR-4):

The FR-4 appliance was developed by Rolf Fränkel for the treatment of skeletal open bite dysplasias during the 1960's. He believed that correction of the faulty postural activity of the orofacial musculature might help correct the associated skeletal deformity. The appliance consists of two buccal shields, two lower lip pads, a palatal bow, an upper labial wire and four occlusal rests on the upper permanent first molars and upper deciduous first molars. It is used in conjunction with lip seal training to achieve over bite correction and elimination of the skeletal dysplasia.[101, 102]

The authors postulate that the appliance achieves these changes in the skeletal pattern through compensatory vertical growth in the condylar region. This is accomplished by the buccal shields, positioned deeply in vestibular sulcus, stretching of the soft tissue leading to an inferior translation of the posterior part and superior translation of the anterior part of the mandible. The lip seal exercises serve to attain lip competence and strengthening of the vertical muscle chain.[103]

A randomized control trial on the effects of the FR-4 appliance showed an average over bite increase of 5.0mm and a relative upper molar intrusion of 1.4mm in the treatment group. The authors also showed a change in the growth direction from downward and backward to upward and forward when compared to the controls. The subjects were instructed to wear the appliance for 18 hours per day and lip seal training was performed by holding a plastic spatula between their lips during homework and whilst watching television. Treatment time amounted to 2 years on average. [104]

A recent review on the orthodontic and orthopaedic treatment of anterior open bites in children, by the Cochrane Collaboration Group, however suggested that there is weak evidence to suggest that the FR-4 appliance with lip seal training is able to correct open bite in children. They warn that the above mentioned study has potential risk of bias and that recommendations for clinical practice cannot be based only on the results of this trial.[105]

3.2.2 Bionator/Activator appliance:

This appliance is a variation on the original design by Andreason and Balters used for Class II orthopaedic correction and is better described as a hybrid appliance. Modification has been made from the original design to allow the incorporation of posterior occlusal coverage. Headgear tubes may also be included with this design. It is therefore suggested to be used to treat skeletal open bite dysplasia concurrently with Class II correction.

A retrospective study[106] evaluating the clinical effectiveness of this appliance found that subjects showed a small decrease in facial height and a mean decrease of 1.3mm in anterior open bite. The investigators concede that the clinicians who partook in this study used the appliance mainly to treat individuals in whom they were concerned that posterior eruption would be undesirable, rather than severe skeletal anterior open bite cases. The appliance seems to restrict the eruption of maxillary molars with little or no effect on the lower molars. The authors suggest that the presence or absence of headgear made little impact (1.0mm) on the amount of open bite closure. This is in direct conflict with another study using this appliance, which suggests that the inclusion of high pull headgear plays an essential role in this treatment modality.[107]

Another clinical controlled trial on the use of this appliance employed a triple combination treatment approach. The activator appliance was combined with occipital high pull headgear and a vertical pull chin cup in the treatment of skeletal open bite subjects. Their results showed an average of 5.14mm reduction in open bite and depression of the maxillary and mandibular dentoalveolar buccal segments during one year of treatment. They further suggest an upward and forward rotation of the mandibular plane as a result of treatment.[108]

A recent systematic review of these studies however has been highly critical of their methodology and conclusions, suggesting that their findings should be viewed with caution.[109]

3.3 Orthodontic appliances

3.3.1 Passive posterior bite blocks:

The landmark primate study by McNamara[110] on five juvenile male Macaca mulatta monkeys first prompted mainstream interest in the use of posterior bite blocks in the treatment of skeletal open bite malocclusion. The authors constructed appliances with various degrees of bite opening ranging from 2mm to 15mm. They were able to demonstrate an inhibition in the eruption of the buccal dentoalveolar segments, although no intrusion occurred; an upward and forward displacement of the nasomaxillary complex; and relatively little effect on the mandibular structures during the experimental period. The magnitude of the changes appeared to be directly related to the amount of bite opening. In another primate experiment the authors investigated the effect of bite blocks with varying thickness and also compared the response of adolescent subjects with juvenile subjects.[111] Their results confirmed the upward and forward displacement of the maxillary complex found in the previous study. Additionally they demonstrated a difference in the maxillary dentoalveolar response between juvenile and adolescent animals. Where the bite blocks only served to arrest eruption of the posterior maxillary teeth in the juvenile animals, it caused extensive intrusion in both arches in the older animals. These results remained stable in the 18 week post experimental follow up period.

A prospective clinical trial studying the effects of two different construction bites found both 5mm and 10mm bite blocks to be effective in the treatment of skeletal open bites and no significant difference between the two in producing an over bite. The 10mm vertical bite block however produced superior results in regards to upward and forward rotation of the mandible and sagittal growth of the mandible. Of significance is the fact that the appliance was unable to achieve a normal over bite (1-1.5mm) in 23% of the 5mm group and 33% of the 10mm group, during 10-13months of treatment.[112] This appears to confirm the findings of Kiliaridis[113] who found the main improvement in over bite with passive posterior bite blocks to occur within the first weeks followed by a plateau period.

3.3.2 Magnetic bite block appliance:

The use of a magnetic appliance in the treatment of skeletal open bite malocclusion was first illustrated in the literature in 1986 by Dellinger.[114] His 'Active Vertical Corrector' (AVC) consists of two removable bite block appliances (maxillary and mandibular) containing four samarium cobalt magnets per arch (two on either side) which the author describes as an 'energized bite block'. The magnets produce a reciprocal repelling, intrusive force of 600-650g per side when placed in the oral cavity. A specially designed headcap and chinstrap is also used when sleeping and at all other times the patient deemed socially fit. Several presented case reports showed the appliance's effectiveness in treating skeletal open bites, through posterior dental intrusion. This allowed closure of the anterior open bite and autorotation of the mandible. This original report was followed by a ten year follow up, demonstrating the long-term stability of the treatment results achieved.[115]

A subsequent prospective clinical trial using a design based on Dellinger's original design, but producing a force of 1500g compared the appliance to passive bite blocks and found superior results in terms of open bite correction, molar intrusion and mandibular autorotation.[113] Another study where the AVC was cemented to the teeth corroborated these results and indicated a 3.2mm increase in over bite, 0.6mm maxillary molar intrusion and 0.4mm mandibular molar in 7.7 months of treatment. However it was also found that changes in angulation and eruption of the incisors contributed significantly to the reduction in open bite.[116, 117]

Kalra *et al.'s* design also used samarium cobalt magnets, but these measured 20x8x2mm (one per side) and a stainless steel wire was included that rested on lingual surfaces of the permanent incisors, to provide intrusion of the entire arch. The magnets were measured to deliver a force of

1080g The authors were able to demonstrate significant molar intrusion, creation of positive over bite and mandibular length increase in four months of treatment.[118]

The MAD IV appliance consists of an upper and lower removable plate which contains neodymium iron boron magnets (two posterior and one anterior).[119] The magnets are configured in repulsion posteriorly and attraction anteriorly, producing a force of 300g. A study investigating the effect of the appliance showed anterior mandibular rotation and significant decreases in lower facial height and open bite parameters.[120]

Although several authors have produced encouraging results using magnetic intrusion appliances, there has been severe criticism in the literature of the appliance. A prominent animal study found no difference in magnetic versus non-magnetic bite blocks in achieving posterior intrusion.[121] Furthermore, it has been shown that there is a dramatic reduction in force levels when the magnets are not in optimal alignment and therefore doubts have been raised as to their effectiveness in the intrusion of posterior teeth.[122] Of concern, are the shearing forces created by the magnets in repulsion. Several authors have indicated that unilateral crossbite or full scissor bite is a frequent and consistent side effect observed with this kind of treatment modality.[113, 118] Animal models have even been able to demonstrate the development of a true skeletal asymmetry in the transverse dimension due to these forces.[123]

3.3.3 Spring-loaded bite block appliance:

Due to the drastic side effects of magnetic appliance some authors experimented with spring loaded bite blocks in the hope of achieving the positive outcomes associated with magnetic appliance, without the dire side effects.

A study comparing spring loaded bite blocks to passive bite blocks and vertical pull chin cup however found no additional benefit to the use of a spring loaded appliance.[124] Another study comparing spring loaded versus magnetic bite blocks found that the magnetic appliance could achieve twice the amount of over bite increase in 3 months than the spring loaded appliance could in one year. In this study the magnetic appliance produced 299-483g of force compared to 264-672g produced by the spring loaded appliance. A possible confounding factor was that the magnetic appliance was cemented to the teeth whereas the spring loaded appliance was removable and only used for twelve hours per day.[125]

3.3.4 Multiloop Edgewise Archwire therapy (MEAW):

This technique, developed by Kim, consists of a 0.016”x0.022” stainless wire which contains a series of loops with both a horizontal and vertical component. The vertical segment serves as a break between the teeth, lowers the load/deflection rate and provides horizontal control, whilst the horizontal component provides vertical control. This technique is used in conjunction with a 0.018” slot twin bracket, vertical elastics and extraction of the second or third molars.[126]

Kim believes a major obstacle to open bite correction to be the mesial inclination of the posterior teeth, especially in high angle patients. The technique endeavours to upright and intrude the mesially inclined posterior teeth after any mechanical blockages have been removed. The anterior vertical elastics (3/16” heavy) serve to counteract the intrusive force produced in the incisor region by the archwire. Kim showed several successfully treated cases in his 1987 report on the introduction of the technique.[127]

A cephalometric study comparing the effects of MEAW therapy to controls found an increase in the upper and lower anterior dentoalveolar height and decrease in the lower posterior dentoalveolar height, but not the upper posterior height. The entire dentition was moved distally and the interincisal angle was decreased. The open bite is therefore corrected by changing the occlusal plane and distally uprighting the teeth. MEAW therapy however had no significant impact on the skeletal pattern.[128]

3.3.5 Fixed appliances and elastics:

Some of the earliest treatment modalities suggested for the treatment of anterior open bite treatment consisted, of the use of fixed appliances in conjunction with anterior vertical elastics to extrude the incisors and achieve a positive over bite.[24, 36, 42] Even in recent times this treatment modality has been suggested in the correction of open bite problems.[129] Clinicians are however well aware that the use of anterior elastics and the associated elongation of the incisors is often extremely detrimental to the facial and smile aesthetics in patients with skeletal anterior open bite dysplasia, where frequently the anterior dentoalveolar is already excessive and the patient shows excessive gingiva on smiling. An investigation on the treatment stability of anterior open bite correction has also shown this method to be associated with a high relapse potential.[130]

Several techniques based on the concepts of Kim's MEAW therapy[127] and Enacar's reverse curve archwires[131] attempt to use anterior vertical elastics to counteract the reciprocal intrusive effects of the archwire on the incisors, thereby obtaining intrusion of the posterior teeth. Cephalometric evaluation of these techniques has however shown the main mechanism of over bite correction to still be extrusion and retroclination of the incisors, with little or no posterior intrusion.[128, 132]

3.3.6 Other tooth borne intrusion appliances:

Stellzig and co-workers[133] describe a case report using an Elastic Activator. It consists of a removable maxillary appliance where the posterior bite blocks have been replaced by elastic rubber tubes 8mm in diameter and 1.5mm thick. The appliance was to be worn for 14 hours per day and the rubber tubes changed every 2-3months. No mention was made of the amount of molar intrusion that occurred or the force exerted by the appliance.

Gurton and co-workers[134] investigated the use of a removable acrylic appliance, the Molar Intruder, for the treatment of anterior open bite malocclusions in growing patients. The appliance consisted of a removable maxillary appliance with Adams clasps on the maxillary premolars and molar intrusion springs on the upper and lower molars, bent from 0.7mm stainless steel wire. The intrusion springs were activated to produce a force of 110g if only the first molars were present or a force of 180g if both first and second molars were present. Patients were instructed to wear the appliance full time apart from meals. Patients were seen at 3 weekly intervals to adjust and reactivate the springs. Average treatment time was 5 months and was followed by full fixed appliance therapy using MEAW. Results showed a mean maxillary molar intrusion of 1.86mm, a mandibular molar intrusion of 1.04mm and an over bite increase of 4mm. When the first and second molars were included the average intrusion was nearly halved.

In a novel adaption of the Jasper Jumper™ appliance Carano[135] attached the two ends of the elastic module to the auxiliary tubes of upper and lower first molar bands. When the patient occludes the elastic module flexes, developing a reciprocal intrusion force of 600-900g. Adverse forces are counteracted by an upper transpalatal and a lower lingual arch. He named the appliance the rapid molar intruder (RMI). Two case reports (one adolescent and one adult) demonstrated molar intrusion of 2mm and 1.5mm respectively, in both molars. Over bite increase was 6.7mm and 3.2mm for each case respectively.

3.4 Extraction treatment

Traditionally extraction treatment, with removal of first premolars, has frequently been indicated by clinicians in the treatment of skeletal anterior open bite malocclusion, even when crowding is deemed to be mild.[28, 34, 36] It was thought that extraction of the first premolars, with protraction of the first molars towards the front of the palatomandibular wedge, may lead to an anterior rotation of the mandible, thereby simultaneously improving the vertical over bite relationship and the frequently observed Class II relationship.[136]

This assumption has however been proved to be false by several retrospective cephalometric studies. These studies found no differences in the molar heights, anterior facial heights and mandibular plane angle between extraction and non extraction subjects. They suggested that the lack of mandibular rotation was due to compensatory extrusion of the molars during treatment, negating the effect of the forward movement. Correction of the anterior open bite was therefore solely achieved by lingual tipping and extrusion of the incisors.[137-139]

Several case reports have suggested that extraction of first molars, especially in cases where the open bite extends to the posterior teeth, would lead to anterior rotation of the mandible. This has subsequently been substantiated in a recent prospective clinical trial where the effects of first premolar, second premolar and first molar extraction treatments were compared. The authors found no rotation of the mandible in cases where first premolars were extracted, but significant closing rotation of the mandible in both the second premolar and first molar group, with the rotation in the first molar group being slightly greater than that of the second premolar group.[140]

Second molar extraction treatment has also been suggested in the literature as a method of reducing the vertical dimension, improving the over bite and the position of the third molars.[127] This could not be proved in a study assessing extraction of second molars and the vertical dimension.[141]

3.5 Combination Orthodontic and Orthognathic surgical treatment

It has been proposed that 90% of patients with skeletal anterior open dysplasia are best treated by a combination of orthodontic and orthognathic surgical procedures.[142] Data from the University of North Carolina Dentofacial Clinic from 1979-1998 suggests that individuals with skeletal open bite problems were more likely to seek and receive surgical-orthodontic treatment than most other deformities and that these patients constitute nearly 25% of all patients who underwent surgical treatment.[143]

Several types of surgical procedures exist to address the correction of skeletal open bite dysplasias. The type of procedure employed will usually depend on the specific facial and morphological open bite characteristics present in each patient. The type of surgery chosen should endeavour to correct the maximum amount of abhorrent features without compromising other features.

As excessive lower face height is the primary distinguishing characteristic of most patients with a skeletal open bite, it stands to reason that reducing this lower face height should be the main objective of any surgery. Most often the maxilla is the principal focus of surgery in skeletal open bite dysplasia as the vertical development of the nasomaxillary complex is nearly always excessive in these individuals.[144]

Superior maxillary surgical repositioning can be achieved, either through a total (Le Fort I) or segmental maxillary osteotomy. Le Fort I maxillary osteotomy is most frequently utilized as it allows correction of both anterior and posterior vertical excess and shows excellent stability. Segmental maxillary osteotomy may be employed either as a two or three segment procedure. Two segments allow the maxilla to be widened as it is moved superiorly whilst three segments is necessary when a vertical step in the arch needs to be corrected or in cases which already have adequate anterior incisor and gingival display. When segmental osteotomies are planned it is normally required to level and align within segments and create root separation for the surgical cuts during pre-surgical orthodontics.[145-147]

When the maxilla is positioned superiorly the mandible rotates around the horizontal condylar axis so that the chin moves in an upward and forward direction, thereby increasing chin projection. This might be beneficial in the case of a Class II malocclusion or detrimental in case of a Class III. A second mandibular procedure, in the form of a bilateral sagittal split osteotomy (BSSO), might be required to either lengthen the jaw if it is both small and rotated or shorten the jaw if it is originally large and rotated. A single mandibular procedure is rarely used as rotating the mandible around the osteotomy site interferes with and lengthens the pterygo-masseteric muscle sling which is notoriously unstable. Also, this would not address the vertical maxillary excesses and increased lower face height most often associated with skeletal open bite problems.[146, 147]

Some surgeons advocate counter clockwise rotational repositioning of both the maxilla and mandible thus improving the palatal, occlusal and mandibular plane angle, as well as the gonial angle. Theoretically this could lead to neuromuscular adaption in a way which isolated mandibular surgery cannot and although anecdotal case reports are available no long-term independent scientific data exists as to the stability of this procedure.[148]

Adjunctive procedures that can be used in conjunction with the above mentioned procedures include lower border mandibular osteotomy (genioplasty) to reposition the chin superiorly, surgically assisted maxillary expansion (SARME) as a first stage procedure in patients who also have a maxillary transverse deficiency and tongue reduction soft tissue surgery in cases of macroglossia. Maxillary anterior segment osteotomy, mandibular anterior and/or posterior sub-apical osteotomies have also been described in the literature, but are seldom used these days.[149]

3.6 Muscle exercise treatment

Muscle exercises, either as a primary treatment modality or as an adjunct to other interventions, has been advocated by several authors as effective in the treatment of anterior open bite malocclusion, during the mixed dentition.[150-155] These authors subscribe to the philosophy that weak masticatory muscles are a primary aetiological factor in the development of a skeletal open bite malocclusion. Muscle exercises generally consist of either lip seal training or some sort of chewing/clenching exercise.

Lip seal training is usually used as an adjunctive treatment modality and aims to improve the lip seal and achieve lip competency, reduce mentalis hyperactivity during swallowing, eradicate tongue thrust swallow and increase the over bite. Its use has been described in several studies and typically consists of the patient consciously attempting to hold their lips together continuously during the day, lip stretching exercises or the holding of an object between the upper and lower lip to increase the peri-oral muscle strength.[101, 102, 108, 155]

Muscle clenching or chewing exercise obviously target the muscles of mastication in an attempt to control the vertical dimension during appliance therapy or modify the skeletal structures in prepubescent individuals exhibiting the characteristic traits of skeletal open bite dysplasia. Clenching exercises commonly consists of several sets, with multiple repetitions, of continuous isometric clenching for a prescribed amount of time. This is done either with only the teeth together or using a soft bite wafer. Although some authors believe that clenching produces both dental and skeletal changes, others are of the opinion that the effects are mainly dental.[153, 154] Chewing exercises on the other hand involve the chewing of hard gum or resin, typically for several hours per day. Some authors using this modality during the mixed dentition phase have reported spectacular skeletal changes on a number of occasions, but concede that this treatment was not successful in all patients treated.[48, 151] The biggest caveat in success, evidently still remains patient cooperation and compliance.

3.7 Stability of treatment

3.7.1 Non-surgical orthodontic treatment

The treatment of anterior open bite malocclusion, although challenging, has often been overshadowed by the frustrating and sometimes seemingly impossible task of maintaining the achieved treatment results. Early authors recognised this difficult challenge and suggested that relapse may be due to continued increase in the posterior maxillary facial height and subsequent downward and backward rotation of the mandible.[156]

The available literature seems to report a wide range in the stability of non-surgical treatment ranging from 75-93%. The mean long-term follow up stability of anterior open bite treatment, with positive over bite, from the literature seems to suggest a figure of 75%.[157] These differences in reported success rates have been attributed to various factors including definition of open bite and measurement method, post treatment growth, dentoalveolar relapse and type of treatment modality. Interestingly, none of the available studies mentioned the type of retention used and no study could be found on the possible influence of different retention strategies on anterior open bite treatment stability.

Most authors agree that relapse of treated anterior open bite malocclusion to be multifactorial with neither pre-treatment open bite nor any other single parameter or facial form being able to reliably predict post treatment stability.[130, 158] One study however suggests the use of a complex mathematical statistical equation to accurately predict treatment outcomes in 88% of prepubertal, 74% of pubertal and 94% of post-pubertal patients.[159] Another proposes the basal width of the symphysis and the NTGoGn angle to be predictive of likely stable treatment outcomes.[160]

Research suggests that subjects who do suffer from significant relapse and poor post treatment stability, have several common characteristics relating to posttreatment changes. These changes include reduced mandibular anterior dental height, reduced upper anterior facial height, increased lower anterior facial height due to molar extrusion (mandibular and/or maxillary) or growth leading to backward/downward rotation of the mandible and reduced posterior facial height. Investigation further indicates that over bite stability in most cases is related to long-term anterior dento-alveolar compensation through extrusion. Patients who lack this compensatory mechanism frequently experienced open bite relapse. It is therefore advised that anterior dentoalveolar extrusion be minimised and retroclination of the anterior teeth be optimised to allow for maximum posttreatment compensatory potential.[157, 158, 161]

Specific non-surgical treatment modalities that have been investigated in terms of post treatment stability reveal interesting results. Relapse after activator treatment concurred with stability studies, finding stability to be largely associated with dental compensation and relapse to be associated with backward rotation of the mandible after treatment.[162] Results of an investigation into tongue crib therapy in growing and non-growing subjects showed a relapse rate of 17.4%. The authors postulated the increased stability to be due to permanent modification of the tongue position or posture.[163] Evaluation of MEAW treatment suggests two year follow up stability to be 93%, although these results should be viewed with caution due to small sample and high dropout rates. Comparison of extraction versus non extraction treatment revealed that extraction treatment was more stable than non-extraction treatment, with 75% and 62% stability respectively. It is proposed that the increased stability be due to greater retraction of the maxillary and mandibular incisors and less extrusion of the mandibular incisors.[164, 165]

Recent research has suggested treatment of mild anterior open bites as a result of relapse, by means of occlusal adjustment. The authors suggest that occlusal adjustment after twenty one years of age will lead to stability in nearly 70% of relapsed patients, with no change in the long-term in dentinal sensitivity.[166] Orofacial myofunctional therapy has also been suggested as a means to reduce post treatment open bite relapse. A recent study proposes a 96% stability rate in patients treated with this modality, showing a mean relapse of 0.5mm in the experimental group compared to 3.4mm in the control group.[167]

3.7.2 Combined orthodontic-orthognathic surgical treatment

Pooled results from the literature suggest 82% treatment stability for combined orthodontic-orthognathic surgical treatment twelve months or more post-operatively.[157] Although this is slightly greater than that of non-surgical treatment modalities one would expect higher stability rates, especially given modern rigid internal fixation techniques. As would be expected, investigation has revealed that instability of open bite surgical treatment was largely due to dentoalveolar changes rather than skeletal changes as remodelling at the osteotomy site is generally completed two to four months after surgery. As with non-surgical treatment it appears that stability, or lack thereof is mainly due to the anterior dental compensatory potential of the individual in response to unfavourable posterior dental changes such as posterior extrusion or transverse collapse, that often occur after surgery.[168, 169] Again, no pre-surgical predictor could be found for post treatment stability. Some authors however suggest the aetiology of post-surgical relapse to be more complex, implicating factors such as poor muscle adaption, bone healing problems, improper positioning of the bony segments, soft tissue tension against the mobilized segments and temporomandibular changes.[170]

A large multi-centre study on 267 patients, followed for a mean period of 69 months post-operatively (range 20-210 months) found an average over bite of 1.24mm and the presence of an anterior open bite in 19% of cases at the longest follow up. They concluded that gender, age, growth, orthodontic treatment, amount of surgical displacement of the maxilla, maxillary segmentation, period of intermaxillary fixation (IMF) or additional genioplasty had no influence on the stability of treatment. Orthodontic expansion prior to surgery however, did result in greater relapse, thereby providing reason to favour, surgically assisted expansion or segmentation procedures. The maxilla showed greater stability in the transverse than vertical dimension. Vertical stability of the maxilla was improved with rigid internal fixation (RIF) over wire fixation and was found to be greater after an isolated Le Fort I intrusion osteotomy compared to bimaxillary surgical procedures. Mandibular stability was also greater after bimaxillary procedures with the use of RIF. The authors finally concluded that dento-alveolar changes continued to occur long-term, but these were not indicative of skeletal instability.[171] A subsequent study by these authors highlighted the alarming frequency of condylar remodelling and resorption in anterior open bite individuals receiving combined orthodontic-orthognathic surgical treatment. Their results concluded that 23.6% will experience condylar remodelling, 7.7% unilateral and 7.7% bilateral condylar resorption. Female patients with severe anterior open bite, high mandibular plane angle and small posterior to anterior facial height, undergoing a bimaxillary procedure were especially prone to these complications.[172]

Other suggested measures to improve stability include avoidance of posterior intrusion and anterior extrusion of the dentition during pre-surgical orthodontics, the use of RIF over wire fixation for all procedures, additional use of bone grafts to augment the stability of RIF, shortened periods of IMF for 0-3 weeks only, avoidance of anterior, inferior maxillary repositioning with clockwise rotation of the maxilla and correct placement of the condyles in the glenoid fossae during surgery, prior to fixation.[169, 173-175]

4.0 Skeletal anchorage and molar intrusion

4.1 History

The idea of skeletal anchorage is not a new concept. Gainsforth and Higley[176] were the first to suggest the use of implants to augment orthodontic anchorage in 1945. They used vitallium screws to achieve tooth movement in dogs, but had limited success due to screw failure within one month of loading. In 1969 Brånemark *et al.*[177] chanced upon the discovery of bone's high affinity for Titanium and coined the term 'osseointegration'. During the same year Linkow[178] described an intra bony blade implant for orthodontic anchorage, but provided no long-term data. Research into implant technology over the subsequent decade was predominantly in the field of prosthodontics, with little mention of implants for orthodontic anchorage reported in the literature. It wasn't until 1983 when Creekmore and Eklund published the first clinical case report of skeletal anchorage. These authors used elastic thread connected to a vitallium screw, implanted below the anterior nasal spine, to intrude the maxillary incisors to resolve a deep bite in an adult human patient.[179, 180]

In 1997 Kanomi[181] pioneered the first mini-implant designed specifically for use in orthodontics. The following year Costa *et al.*[182] introduced a 2mm titanium miniscrew with a bracket like head that could be placed with a screwdriver directly through the mucosa, flaplessly, and could be loaded immediately. This allowed for either direct or indirect anchorage usage. Other noteworthy historical developments in the evolution of skeletal anchorage include reports on midsagittal palatal implants for anchorage by Wehrbein *et al.* [183], the use of zygomatic ligatures by Melsen *et al.*[184] in the intrusion and retraction of maxillary incisors and the development of the Skeletal Anchorage System (SAS) by Sugawara, which he derived from existing rigid internal bone fixation technology.[179, 185]

This first published report in the literature on molar intrusion, using skeletal anchorage, was by Umemori *et al.* in 1999.[186] The intrusion was achieved using the SAS pioneered by the Japanese group headed by Sugawara. They showed several cases in which the lower molars were intruded by 3mm to 5mm, using 500g of force per side. Intrusion was accomplished in 5 to 9 months with no side effects to the rest of the dentition. Following on from this Erverdi *et al.*[187] successfully demonstrated the intrusion of maxillary molars in humans, using zygomatic buttress skeletal anchorage. They used skeletal anchorage plates similar to the SAS, but anchored to the Zygomatic buttress, bilaterally, to achieve the desired maxillary first molar intrusion. Using this system the authors achieved 3mm of intrusion in seven months of treatment, using a force of 200g per side.[187] With the use of miniscrews gaining more widespread acceptance and becoming part of routine clinical practice in the new millennium, Paik *et al.* [188] were the first to demonstrate the use of miniscrews only (buccal and palatal) in the treatment of a skeletal anterior open bite dysplasia by molar intrusion. They were able to achieve 3mm of intrusion in their case report, using 150-200g of force. The treatment duration however was not specified by the authors.[188]

4.2 Animal studies

Several authors have investigated the effects of tooth intrusion with skeletal anchorage modalities, using animal models. Southard *et al.* [189] were the first to explore osseointegrated implants and the ability to effect intrusion of teeth in eight adult mongrel dogs. They applied 100g of intrusive force to the third premolars bilaterally. On one side they used traditional tooth borne anchorage from the fourth premolar, whilst on the contralateral side they used an osseointegrated implant, which had been placed in the site of the previously extracted fourth premolar. Over the 16 week experimental period, they demonstrated intrusion of 2.8mm on the implant side which contrasted to intrusion of 0.3mm on the dental side which was accompanied by 3.1mm of extrusion of the anchor teeth. The authors concluded that rigid endosseous implants offer superior anchorage for the orthodontic intrusion of teeth compared to dental anchorage.

Ohmae *et al.* [190] considered the possibility of using miniscrews (1.2x2mm) for the intrusion of mandibular third premolar teeth in three adult male beagle dogs. Using miniscrews on both the buccal and lingual side in conjunction with Nickel Titanium (NiTi) closed coil springs, which developed 150g of intrusive force, they were able to generate an average 4.5mm of intrusion of the teeth in the 12-18weeks of the experimental period. They consequently concluded that miniscrews offered a reliable anchorage source for orthodontic intrusion of teeth in beagle dogs, with minimal damage to the intruded teeth.

Other animal studies relating to skeletal anchorage and intrusion in the animal model have mainly focused on the radiographic and histological effects of intrusion on the intruded teeth, the peri-dental soft and hard tissue structures and the implants themselves. They all concluded that skeletal anchorage offered a safe and reliable treatment modality for the orthodontic intrusion of teeth. The side effects associated with this modality, like root resorption, are minimal and comparable to traditional anchorage methods.[191, 192]

4.3 Human studies

An online search of the literature, using a respected medical database search engine (Ovid MEDLINE®), revealed 28 published articles in the English literature on molar intrusion using skeletal anchorage between 1998 and March 2011. A summary of which can be found in the table below (Table 1). Of the published literature, 22 articles are presented as individual case reports.

One study takes the form of a retrospective assessment of 22 patients who had undergone orthodontic treatment to intrude over-erupted maxillary molars at the National Taiwan University.[193] Eighteen of the patients received both buccal miniplates and palatal miniscrews, whilst the other four were treated with both buccal and palatal miniscrews. The intrusive force of 150-200g was applied to the first maxillary molar using elastic chains. Data was obtained from 3D analysis of scanned dental casts, which had been superimposed on the palatal rugae. Results showed considerable variation with intrusion ranging from -3.68 to 8.67mm. The mean amount of intrusion at the maxillary molar was 3 to 4mm and mean treatment time was 7.6months (range 5-12 months)

Five prospective studies were found in the available literature, of which the first was published in 2002. Sample sizes varied considerably, ranging from 4 to 12 subjects, as did skeletal anchorage devices, intrusion auxiliaries, intrusive force, treatment time and rate of intrusion.

The prospective studies from the literature can be summarized as follows:

Sherwood *et al* .[194] studied maxillary molar intrusion in four adult patients with anterior open bite malocclusions. The subjects underwent implantation of bilateral zygomatic buttress miniplates which were loaded 8 weeks post-operatively. The intrusive force (magnitude not mentioned) was applied using elastomeric thread. Results showed a mean maxillary molar intrusion of 1.99mm (range1.45-3.32mm) with a mean closure at the incisors of 3.62mm (range 3.0-4.5mm), in 5.5months of treatment.

Erverdi *et al.* [195] undertook a pilot study to intrude the maxillary posterior dentition of ten patients (17-23 years old) with a mean open bite of 0.6mm (± 2.27mm). The skeletal anchorage used consisted of bilateral zygomatic buttress, I-shaped, titanium miniplates loaded 4-7days post-operatively. The intrusive force of 200g per side was applied via 9mm closed NiTi coil springs. The resultant maxillary molar intrusion was on average 2.6mm (± 1.39mm) with an over bite increase of 3.7mm (± 2.4mm). Treatment time on average was 5.1months.

Kuroda *et al.* [196] prospectively studied the intrusion of the maxillary posterior dentition in ten adult females (mean age 21.6 years) with an anterior open bite malocclusion of 5.2mm on average (±1.8mm), by means of either SAS miniplates or titanium miniscrews. The outcomes were also compared to thirteen patients who had undergone a combination of Le Fort I and mandibular osteotomy, orthognathic surgical treatment. The skeletal anchorage devices were loaded 4 weeks post-operatively with an intrusive force of 150g per side, through the use of elastic chain. Results showed an average of 3.6mm of molar intrusion (± 1.6mm), 6.8mm over bite increase (± 1.7mm) and no elongation of the incisors. These results were achieved in 7 months of active intrusion. In comparison the surgery group achieved similar results in molar superior positioning and over bite increase, but with significant elongation of the incisors and increased treatment time. The authors concluded that treatment of open bite malocclusions with molar intrusion using skeletal anchorage achieves superior morphological improvement over orthognathic surgery.

Erverdi *et al.* [197] evaluated maxillary posterior dentoalveolar segment intrusion in 11 anterior open bite subjects with a mean age of 19.5 years. The skeletal anchorage used consisted of I-shaped zygomatic miniplates, bilaterally. The devices were loaded 7-10 days post-operative, using two 9mm NiTi coil springs on each side, delivering an intrusive force of 400g per side. Results suggest a mean molar intrusion of 3.6mm (±1.4mm) and an over bite increase of 5.1mm (±2.0mm). Average treatment time was 9.6 months (±1.9 months).

Xun *et al.* [198] employed both maxillary palatal and mandibular buccal miniscrews to evaluate the posterior dentoalveolar intrusion in 12 subjects (mean age 18.7 years). Loading of the miniscrews, with 150g of force per side, commenced two weeks after implantation. The maxillary first molars were intruded on average 1.8mm, mandibular molars 1.2mm and the over bite increased on average by 4.2mm. The mean treatment time was 6.8 months (±1.1 months).

Pertinent points that may be gleaned from the combined body of literature suggest: 1.The use of several possible skeletal anchorage devices including: zygomatic buttress miniplates, a combination of buccal miniplates and palatal miniscrews, a combination of buccal and palatal miniscrews, buccal miniscrews, palatal miniscrews or prosthetic dental implants. 2. The adaptation of several existing orthodontic auxiliaries to apply the required intrusive force including: elastic/powerchain, elastic thread, elastic bands, closed NiTi coil springs or coated elastic thread. 3. Applied intrusion force ranging anywhere between 100-500g. 4. Treatment times ranging from 5-13 months. 5. A calculated, combined rate of intrusion, averaging out at 0.53mm per month (0.23-1.0mm per month).

Table 1: Summary of literature on molar intrusion using skeletal anchorage, in humans.

Author/Year	Study design/ Subject number	Teeth intruded	Type of skeletal anchorage	Intrusion auxiliary	Force	Treatment duration	Amount of intrusion	Rate of intrusion
Umemori *et al.* . 1998[186]	Case study n= 2	Lower 1st and 2nd molars	Miniplates (SAS)	Elastic thread	500g/side	5months 9 months	3.5mm 5.0mm	0.7mm/month 0.56mm/month
Erverdi, Keles. 2002[187]	Case study n=1	Maxillary posterior teeth (5-7)	Zygomatic Miniplates (Leibinger)	9mm NiTi coil spring	200g/side	Not stated	3mm	Unknown
Sherwood 2002[194]	Prospective trial n=4	Maxillary molars	Zygomatic Miniplates (Leibinger)	Coated elastic thread	Not stated	5.5months	1.99mm (1.45-3.32mm)	0.36mm/month
Park *et al.* . 2003[199]	Case study n=2	Maxillary second molar	Miniplates Buccal/ Miniscrew Palatal	Powerchain	200-300g	8-12 months	Not stated	0.5-1mm/month
Paik, Boyd 2003[188]	Case study n=1	Maxillary molars	Miniscrews buccal/palatal	Elastic thread	150-200g	Not stated	3mm	Unknown
Sherwood 2003[200]	Case study n=2	Maxillary molars	Zygomatic Miniplates (Leibinger)	Coated elastic thread	Not stated	6.5 months	4.0mm	0.62mm/month
Yao *et al.* . 2004[201]	Case study n=1	Maxillary Left molars	Miniplates Buccal/ Miniscrew Palatal	Powerchain	150-200g	5 months	3.0mm	0.6mm/month
Lee *et al.* 2004[202]	Case study n=1	Maxillary Left molars	Miniscrews Palatal/Buccal	Powerchain	150-200g	7 months	Not stated	Not stated
Park *et al.* 2004[203]	Case study n=1	Maxillary and mandibular molars	Maxillary and mandibular miniscrews	Elastic thread	150g	11 months	Not stated	Unknown
Chang *et al.* 2004[204]	Case study n=1	Maxillary molars	Miniscrews buccal/palatal	Elastic bands	100g	5 months	3.25mm	0.65mm/month
Erverdi *et al.* 2004[195]	Prospective trial n=10	Maxillary molars	Zygomatic Miniplates (Leibinger)	9mm NiTi coil spring	200g/side	5.1 months	2.6mm mean	0.51mm/month
Kuroda *et al.* 2004[205]	Case study n=1	Maxillary and mandibular molars	Maxillary and mandibular miniscrews	Elastic chain	Not stated	13 months	3mm upper/ 3mm lower	0.23mm/month
Yao *et al.* 2005[193]	Retrospective study n=22	Maxillary molars	Miniplates Buccal/ Miniscrew Palatal	Elastic chain	150-200g	7.6months mean (5-12 months)	3-4mm (3.68-8.67mm)	0.46mm/month mean
Jeon *et al.* . 2006[206]	Case study n=1	Maxillary and mandibular left molars	Maxillary and mandibular miniscrews	Elastic thread	200g	6 months	3mm	0.5mm/month
Lin *et al.* . 2006[207]	Case study n=2	Maxillary molars	Miniscrews Palatal/Buccal	Powerchain	400g	5 months	5mm	1.0mm/month
Kato and Kato 2006[208]	Case study n=2	Maxillary molars	Prosthetic implants	NiTi coil spring	300g	13 months	6mm	0.46mm/month
Park *et al.* 2006[209]	Case study n=1	Maxillary and mandibular molars	Maxillary buccal/palatal and mandibular miniscrews	Elastic thread	100g	7 months	2mm	0.29mm/month
Erverdi *et al.* . 2006[210]	Case study n=1	Maxillary posterior teeth (4-7)	Zygomatic Miniplates	9mm NiTi coil spring	400g/side	7months	3.6mm	0.52mm/month

Erverdi *et al.* . 2007[197]	Prospective trial n=11	Maxillary posterior teeth (4-7)	Zygomatic Miniplates	9mm NiTi coil spring	400g/side	9.6 months ± 1.9 months	3.6mm ± 1.4mm	0.38mm/month
Kuroda *et al.* . 2007[211]	Case study n=1	Mandibular molars	Miniscrews	Elastic chain	150g	6 months	3mm	0.5mm/month
Xun *et al.* . 2007[198]	Prospective trial n=12	Maxillary and mandibular molars	Maxillary palatal and mandibular miniscrews	Powerchain	150g	6.8 months ± 1.1 months	1.8mm upper 1.2mm lower	0.27mm/month upper 0.18mm/month lower
Kravitz *et al.* . 2007[212]	Case study n=1	Maxillary molars	Miniscrews Palatal/Buccal	7mm NiTi coil spring	150g	6 months	4.4mm	0.73mm/month
Choi *et al.* . 2007[213]	Case study n=1	Maxillary and mandibular molars	Maxillary buccal/palatal and mandibular miniscrews	Elastic chain	Not stated	4 months	Not stated	Unknown
Takano-Yamamoto, Kuroda 2007[214]	Case study n=2	Maxillary molars	Maxillary buccal miniscrews	Elastic chain	200g	6 months	3.0mm	0.5mm/month
Kuroda *et al.* . 2007[196]	Prospective trial n=10	Maxillary molars	Zygomatic Miniplates or buccal miniscrews	Elastic chain	150g	7months	3.6mm ±1.6mm	0.51mm/month
Park *et al.* . 2008[215]	Case study n=1	Maxillary molars	Maxillary buccal miniscrews	Powerchain	200g	5 months	2.0mm	0.4mm/month
Tuncer *et al.* . 2008[216]	Case study n=1	Maxillary molars	Zygomatic Miniplates	NiTi coil spring	250g	2.5 months	4.0mm	1.6mm/month*
Ohura *et al.* . 2011[217]	Case study n=1	Maxillary molars	Zygomatic miniplates	Elastic chain	Not stated	10 months	3.1mm	0.31mm/month

*Coticotomy assisted

4.4 Physiological effects of molar intrusion

4.4.1 Periodontal implications

The literature reports conflicting evidence regarding the periodontal effects of intruding teeth.[218] However, researchers have been able to show new connective tissue attachment formation in periodontally affected monkeys after surgical treatment of the periodontal pockets and intrusion of the affected teeth. They did stress good oral hygiene to be critically important if new periodontal attachments were to be formed and demonstrated that in the absence of good oral hygiene, intrusion of teeth would ultimately lead to periodontal breakdown and marginal bone loss.[219] A study in dogs on the effects of dentoalveolar intrusion on the alveolar bone crest showed that apical pressure from supracrestal fibres during intrusion resulted in apical bone remodelling and maintenance of the gingival pocket depth.[220] Isolated case reports from the literature have also been able to demonstrate an improvement in attachment levels of patients with horizontal bone defects.[221]

4.4.2 Pulpal neurovascular implications

Research has demonstrated that several neurovascular changes occur in the pulp during orthodontic intrusion. These changes are thought to occur mainly as a direct result of capillary compression at the apical foramen which leads to a reduction in intrapulpal blood flow, circulating nutrients and oxygen. It has been shown that short term intrusion (7days) leads to an increase in aspartate aminotransferase (AST), an enzyme normally confined to the cell wall, but released during cell necrosis. An increased response threshold to electrical pulp testing was also observed.[222] Long term intrusion forces to teeth result in a reduction in the number of capillaries at the apical foramen, vacuolization of the odontoblasts and a reduction in the predentin layer. There was however no deleterious reduction in innervation parameters. These changes appear to be transient in nature and after a sufficient retention period, angiogenesis occurs at the foramen, the circulatory pattern is restored and reparative changes occur within the pulp. Intrusion therefore seems to have no long term detrimental neurovascular effects on the dental pulp.[223]

4.4.3 Root resorption

Orthodontically induced inflammatory root resorption (OIIRR) is a risk associated with all types of orthodontic tooth movement. Although our ability to predict the OIIRR in specific individuals is poor the literature does seem to suggest that the risk is higher with certain types of tooth movements and in certain morphological groups. Unfortunately, intrusion is proposed to be one type of tooth movement most highly correlated with an increased risk of OIIRR. This is thought to be due to the fact that even when forces are kept to a minimum, the stress per unit surface area is still exaggerated in the tooth root as the force tends to be concentrated around the apical area during intrusion. Research also suggests that skeletal anterior open bite individuals are at greater risk of developing root resorption during orthodontic treatment than individuals with other types of malocclusion.[224]

Animal studies on molar intrusion using skeletal anchorage however, have not supported this view.[191, 220, 225, 226] Radiographic and histological investigations report apical root resorption in animal models ranging between 0.1-0.6mm after molar intrusion. Even significant amounts of molar intrusion (4.2mm) and long treatment durations (7months) did not induce great amounts of resorption. Several authors also found no difference in the amount of root resorption observed between light and heavy forces (50 and 200g per tooth) applied to the teeth, although the literature generally proposes a high correlation between heavy intrusive force and OIIRR.[227]

A retrospective radiographic study compared OIIRR in open bite cases treated by skeletal anchorage molar intrusion versus matched controls treated with fixed orthodontic appliance and no intrusive mechanics. The authors found molar root resorption in the skeletal anchorage group ranging between 0.02-2.49mm. Molar root resorption in the fixed appliance group ranged between 0-1.6mm. This resulted in a mean difference of 0.58mm which, although statistically significant, was found to be clinically irrelevant. To note, measurements for this study were taken from panoramic radiographs and therefore this study should be viewed with caution due to the inherent limitations of such radiographs.[228]

4.4.4 Adjacent anatomical structures

During posterior tooth intrusion clinicians have been greatly concerned with problems that might arise from anatomical structures intimately related to the tooth roots, like the maxillary sinus and inferior alveolar neurovascular bundle. Research however has shown that there is no need for alarm. A recent animal study has shown that even when maxillary teeth were purposely intruded to a point where they encroached on the maxillary sinus, the nasal floor remodelled in an apical direction to maintain its integrity and prevented breaching of the nasal mucosa. The investigators found the remodelling bone around the maxillary molar roots to be lamellar in appearance on the palatal side and woven bone on the buccal side. Histologically, the roots were closely related to the bony wall covering it, whilst the nasal floor mucous membrane was unaffected and maintained its normal histological appearance.[220]

Similarly, animal research on mandibular molar intrusion found that the inferior alveolar neurovascular bundle was not damaged during intrusion. Rather, the inferior alveolar neurovascular bundle relocated inferiorly during the intrusive tooth movement, maintaining its distance from the advancing tooth apex.[229]

4.5 Stability of molar intrusion treatment using skeletal anchorage

Molar intrusion using skeletal anchorage is a relatively new treatment modality; hence, very limited literature exists on the stability of the intrusion results achieved. Sugawara *et al.* [230] were the first to report on treatment stability, suggesting a relapse rate of 30% for mandibular molar intrusion one year after treatment. More recently reports on maxillary molar intrusion relapse have been discussed in the literature with Heravi *et al.* [231] reporting a relapse rate of 19% after 2.1 mm of initial intrusion, 6 months into retention. Lee and Park[232] reported nearly half that rate, with only 10.4% relapse of the initial maxillary molar intrusion one year after treatment.

Baek *et al.* [233] recently were the first to publish an investigation on the long-term stability of maxillary posterior dentoalveolar segment intrusion using skeletal anchorage devices. Their report describes the post treatment changes in nine adult patients (average age 23.7 years), three years after treatment. Fixed lingual retainers were used for all patients and were supplemented with circumferential retainers full time for the first six months, and then night time thereafter. On average the maxillary molars were intruded by 2.39mm and experienced eruption of 0.45mm by the three year follow up period. This equated to a relapse rate of 22.9%, with authors further reporting that 80% of the total relapse occurred in the first year of retention. In parallel with this, the over bite increased by a mean of 5.56mm during treatment, but only relapsed by 1.2mm in three years. The authors recommend the use of an active retainer attaching to the miniscrews to minimise post treatment relapse. They also conclude that maxillary posterior dental intrusion with skeletal anchorage devices is a valid treatment modality, providing long-term stability that is comparable to both surgical and non-surgical treatment outcomes.

5.0 Biomechanics

5.1 Intrusion

Much controversy exists in the literature regarding the optimal force for the intrusion of posterior teeth. Theoretically, light continuous forces in the order of 7-26g/cm² produce the most efficient tooth movement.[234] A recent meta-analysis however concluded that no firm evidence exists in the literature regarding the optimal force required for orthodontic tooth movement, due to the fact that most studies contained several uncontrolled factors and only measured force magnitude, rather than strain produced in the PDL.[235]

Several authors have attempted to quantify the optimal force required for orthodontic intrusion. The proponents of extra oral traction, in the form of headgear, advocate relatively high force magnitudes ranging anywhere from 300-1500g of force. Most however use forces in the range of 400-600g. In terms of traditional intraoral tooth borne mechanics, Burstone[236] suggested 20g of intrusive force for incisors and 50g for canines, whilst Proffit[2] advocates 10-20g of continuous intrusive force. Kalra *et al.* [118] applied 90g of force to intrude molars in children compared to Melsen and Fiorelli[221] who suggested 50g of force for molar intrusion in adults. Use of these extremely light forces was vital in conventional orthodontic mechanics to prevent adverse reactions in the reactive unit, caused by the large reactive moments created by these intrusive force systems.

With the advent of skeletal anchorage these forces could be increased to attain the perceived optimal force system without concern for unwanted side effects in the reactive unit as Büchter *et al.*[237] found miniscrews to remain clinically stable at force levels up to 900g. Using skeletal anchorage, the suggested intrusive force level for single maxillary molars, from literature, appears to be 100-200g (Table 1). Kato and Kato[208] however found 100g of force to be insufficient for en-masse molar intrusion, but smooth progressive intrusion was achieved when the force levels where increased to 300g per side. The literature seems to suggest optimal force levels of 200-500g for en-masse molar intrusion using skeletal anchorage (Table 1).

Concerns regarding force levels during intrusion, root resorption and the effects on adjacent structures have previously been discussed in section 4.4.

The centre of resistance (COR) of the maxillary molars has been described as being located in the furcation area.[238] Any mechanics applied outside of this COR will result in a tipping moment on the tooth.[239] Consequently if force is applied from one side only, ie buccal or palatal, measures need to be instituted to counteract these unwanted tipping forces on the tooth. This can take the form of a transpalatal arch or rapid maxillary expander if the force is applied from the buccal side or a rigid rectangular archwire if applied from the palatal side.

5.2 Orthodontic Miniscrew anchorage

5.2.1 History

Miniscrew implants are derived largely from prosthetic osseointegrated dental implant technology. Kanomi[181] was the first to describe a miniscrew specifically designed for use in orthodontics in 1997. One year later, in 1998, Costa and Melsen[182] described a Titanium miniscrew, 2mm in diameter, with a bracket like head. These screws could be placed with a screwdriver, directly through the mucosa without the need for flap surgery. The screws could then be loaded shortly after placement and be used for either direct or indirect anchorage. Ohmae *et al.* [190] then demonstrated the potential of miniscrews to be used for intrusion in an animal study involving beagle dogs. Paik *et al.* [188] were the first to publish a report on the use of only miniscrews as skeletal anchorage for the intrusion of maxillary molars in the treatment of an anterior open bite malocclusion. Currently there are 48 different miniscrew systems registered with the American Federal Drug Administration (FDA).

5.2.2 Miniscrews versus miniplates

As with several other treatment modalities, much controversy exists as to whether miniscrews or miniplates are better suited as skeletal anchorage devices.

Proponents of miniscrew anchorage suggest the advantages of miniscrews to be numerous. These devices offer a simple insertion and explanation technique. They are relatively affordable and require very little instrumentation for placement and removal. Miniscrews are able to be placed in various anatomical sites, creating the possibility for direct or indirect mechanics. This treatment generally requires a very atraumatic surgical procedure with greater patient comfort and better postoperative sequalae. A study comparing miniscrews to miniplates found that only 50% of the miniscrew subjects reported pain one hour post-operatively, compared to 100% of the miniplates subjects. Pain assessment using the Visual Analogue Scale (VAS) put the pain intensity associated with miniscrews at 19.5, as opposed to 66.4 with miniplates (VAS of pain after 1 day of orthodontic treatment scored 40-50). One day after surgery only 10% of miniscrew subjects still reported pain, with the figure dropping to 0% by seven days. In comparison, 30% of miniplate subjects reported pain on day seven and 10% still reported pain by day fourteen. Miniplates were also more often associated with swelling, speech difficulty, problems with chewing and difficulty in tooth brushing.[240] The cumulative success rates of miniscrew implants average 84% and they are therefore able to offer predictable and efficient treatment outcomes. The ability for orthodontic clinicians to place the miniscrews themselves also presents greater flexibility and more precise control over biomechanics.[241-243]

Advocates of miniplate anchorage propose that this treatment modality is superior to miniscrew implants as it consistently offers success rates of greater than 93%, with less variability than miniscrews. They also feel that they are well tolerated by patients even though this treatment requires two surgical procedures.[244] Their proposed objections related to the use of miniscrew derived anchorage include, rotational instability, possibility of iatrogenic damage, screw migration, screw fracture on removal, mucosal overgrowth and loss of anchorage in the event of screw failure.

5.2.3 Miniscrew placement

Various miniscrew placement protocols have been described in the literature. These protocols vary widely and are very often largely dependent on the design characteristics of the miniscrews. Miniscrews are available in several different lengths, diameters and may be cylindrical, conical or tapering in shape. They may be self-drilling or require pre-drilling, although all miniscrews are self-tapping. Several thread, neck, collar and head designs are also available. Finally implants can be placed using either a flap or flapless procedure.

Research suggests the use of screws greater than 1.2mm in diameter for sufficient strength and resistance to fracture.[243] It has also been shown that miniscrew implants gain most of their retention through cortical bone anchorage with very little stress transferred to the trabecular bone in circumstances where the cortical bone thickness is 1mm or greater.[245, 246] In situations where cortical bone is insufficient, additional retention may be obtained from longer screws. It is therefore recommended that screws of at least 6mm length are used in areas of sufficient cortical bone thickness and 10mm or longer in areas with low bone quality. Self-drilling tapering screw design appears to be superior compared to non-drilling cylindrical or self-drilling conical designs.[247]

Studies investigating surgical procedures have shown no additional benefit in terms of success in using a flap procedure, but associate this approach with significantly higher post-operative morbidity. It is therefore suggested that a flapless transmucosal surgical approach possibly be used routinely in the placement. Pre-drilling has been shown to be unnecessary in all placement sites, except for the posterior mandible where the cortical bone is extremely thick. Even then it is suggested that pre-drilling is limited to a notch that penetrates only the cortical plate, as pre-drilling is associated with heat generation, localised osteonecrosis and ultimately higher failure rates of miniscrews. Lower insertion torque values and greater clinical experience appear to correlate positively with reduced failure rates.[241, 248]

Miniscrews have demonstrated slightly higher overall success rates in the maxilla (88%) compared to the mandible (80%), but no sex differences have been found in miniscrew success rates. Research has revealed greater failure with increased root proximity and it is therefore suggested that miniscrews only be placed in areas with at least 3-4mm interradicular space.[249, 250] Several studies [251-257] agree that the most ideal site for miniscrew placement in the maxilla is between the second premolar and first molar 5-8mm from the alveolar crest, followed closely by the site between the first and second premolar 5-11mm from the alveolar crest. These sites are reported to consistently offer the highest interradicular space, buccolingual width and cortical bone thickness.[251-257] It is further advised that the miniscrew be placed in an oblique direction buccolingually, 30° to 40° to long axis of the maxillary teeth, to achieve greatest bone contact and minimise the possibility for root contact. However, the validity of this is doubtful as oblique insertion would lead to poor neck and collar adaption, which increases the risk for peri-implantitis and the ultimately associated miniscrew failure. One study also recommends placing the miniscrew 0.5-1.0mm distal to the contact point and angling it 10° to 20° to the distal to account for the distally directed curvature of the maxillary posterior teeth.[258]

Several studies advise placing the miniscrews in keratinized gingiva to prevent inflammation and tissue hypertrophy. The periodontic literature however shows the average width of the attached gingiva to be in the order of 3.59-4.99mm around the second premolar and 4.12-5.38mm around the first molar.[259] The width of the keratinized gingiva is further influenced by the stage of the individual’s vertical development, with adolescents generally having a narrower band of attached gingiva compared to adults. It is therefore not always possible to place the miniscrew implant in attached tissues and recent authors proposed placing miniscrews in the mucosa, close to the mucogingival junction where the mucosa can be stretched and held taught during placement, to prevent mucosal bunching and tearing.[260]

5.2.4 Miniscrew loading

Great conflict of opinion exists as to the optimal time before loading with protocols varying from immediate loading to a delay of 149 days. The advocates of delayed loading have their beliefs anchored in the prosthetic implant literature and suggest that greater bone to implant contact, which increases as the surgical site heals, will lead to greater implant stability.[261] Miniscrews however do not need to resist the large masticatory forces (>700N) that prosthetic implants do, and it has been proposed that 5% bone to implant contact is sufficient to resist the forces associated with orthodontic tooth movement.[262] It has been hypothesized that sufficient early stability of miniscrew implants is mainly reliant on mechanical retention and that later stability is then derived from increased bone to implant contact through partial osseointegration. Research has also revealed that immediate loading may stimulate bone turnover and lead to accelerated bone healing compared to unloaded miniscrews.[263, 264]

Early authors[221] suggested that very light forces, in the order of 50g, be used during the initial healing period with immediate loading, before increasing the force to greater orthodontic levels. Recent authors however agree that initial loading of 100-200g to be clinically acceptable for immediate loading, whilst experimental studies have shown stability with immediate loads of up to 600g or 900g.[237, 265, 266]

Laboratory based tests have shown miniscrews to be resilient to very high force levels, with failure occurring at >340N for pullout and >250N for shear testing.[267] These force levels are infinitely greater than any clinically applied orthodontic force level which generally range between 50g to 400g, although most studies employ force levels of less than 200g.[241, 243] Most miniscrew failures are therefore attributable to biological rather than mechanical factors.

5.2.5 Stability and failure of miniscrews

A recent systematic review of the literature reports a mean overall success rate of 83.8%±7.4% for miniscrew stability from the available clinical trial studies.[243] Several parameters relating to success or failure have been investigated, very often, with conflicting results. These variables can be grouped into different categories namely, implant, patient, location, surgery and orthodontic factors.

Several implant related factors have been associated with increased success rates. Implant success rates appear to increase with implant diameter and length.[268] Screw diameter relates partly to the increased resistance to fracture as the diameter increases beyond 1.2mm and partly to the increased cortical anchorage derived from diameter increase. In areas of sufficient bone quality screw length has little effect, but in areas with very little cortical bone increase miniscrew length equates to significantly greater retention and success.[269-271] A trade-off nonetheless exists between increased miniscrew length and diameter and available anatomical implant sites. Miniscrew shape, thread pitch and fluting also have a theoretical influence on miniscrew success with decrease pitch, thread fluting and tapering design associated with increased pullout strength and removal torque.[272]

Patient associated factors remain controversial with several authors finding no significant difference in miniscrew survival related to patient sex, age, sagittal classification, arch length discrepancy and right or left side.[273-277] Others however disagree and suggest that failure rates are increased in younger adolescent patients due to decreased cortical bone thickness.[278-280] Consensus does exist regarding vertical facial pattern with authors suggesting individuals with a hyperdivergent open bite facial pattern, increased mandibular plane angle, high Frankfurt horizontal plane and low upper gonial angle experiencing greater miniscrew failures than average. This is again related to the decreased cortical bone thickness related to individuals with a hyperdivergent skeletal open bite facial pattern.[273, 275, 277]

Conflicting data exists as to which jaw represents the higher success rate for miniscrew placement. Several studies have found placement in the maxilla to be more stable than the mandible, postulating that this is due to greater heat generation associated with miniscrew placement in the mandible, which in turn leads to osteonecrosis, loss of stability and explantation of the miniscrew. Those who have found higher success rates in the mandible suggest that this is due to reduced cortical bone thickness and lack of stability in the maxilla. Research also suggests the sites with the highest success rates to be between maxillary second and first premolar, maxillary second premolar and first molar and mandibular first and second premolar.[257, 279] Several earlier authors encourage placement in keratinized tissue to avoid gingival hyperplasia leading to peri-implantitis, whilst recently it has been shown that placement in unattached mucosa close to the mucogingival junction may be equally successful, provided patient hygiene is adequate. Root proximity has also been shown as a major cause of miniscrew failure and clearance of at least 1mm is suggested either side of the miniscrew implant.[281]

Most studies found equivocal results for flap surgery compared to flapless surgery, although one study reports lower success rates for 2-stage surgery compared to 1-stage surgery.[282] Flap surgical procedures were however associated with significantly greater post-operative morbidity when compared to flapless procedures. Authors also report comparable outcomes for pre-drilling versus self drilling, but stress that some areas like the posterior mandible might require at least cortical notching prior to miniscrew placement, due to the thickness of the cortical plate. Survival analysis has also revealed improved success once an operator has placed more than 40 miniscrews and a steep learning curve is definitely involved in the successful placement of miniscrew implants.[278]

Miniscrew loading has already been discussed in detail in section 5.2.4, as has its relation to success rates. Clinical studies suggest placing the miniscrew implant at a 30° to 40° angle to the long axis of the tooth to achieve maximal bone contact and avoid root approximation. This is in conflict with in vitro results with one study finding greater resistance to force with placement perpendicular to the long axis of the tooth and another with placement in the line of action of the force.[267, 283] Literature suggests that miniscrew failure due to excessive force is a rare occurrence, but that failure in response to loading forces is often due to torsional stresses which result in an unscrewing moment and loosening of the miniscrew.[278, 284]

Review of the available research seems to suggest that a great number of the total miniscrew failures occur within the first one or two months of placement and that the majority of failures transpire prior to four months after placement. [274, 276] Late failures have been ascribed to tooth movement leading to root proximity which in turn will increase the likelihood of implant failure.

5.2.6 Adverse effects associated with miniscrews

The incidence of adverse effects from miniscrew placement is generally low, and with proper placement care and precaution, should be a rare occurrence in clinical practice. Adverse events arising from miniscrews can broadly be categorized into; complications during insertion, complications under orthodontic loading, soft tissue complications and complications during removal.[285]

Trauma to the periodontal ligament or tooth root is probably one of the most frequently reported difficulties associated with skeletal anchorage as any interradicular miniscrew placement carries inherent risk of trauma to these structures. Potential complications included loss of tooth vitality, root fracture, ankylosis or osteosclerosis. Research however suggests that the greatest depth of root penetration to be 0.25mm with maximal force, when using manually driven self drilling miniscrews.[260] Several recent studies[283-286] have evaluated the effects and response of intentional root damage caused by miniscrew implants. The authors concluded that: 1.Trauma to the outer layer of the root without pulpal involvement was unlikely to negatively impact on tooth prognosis even with intentional root penetration. Complete repair usually occurred within 6-12 weeks of miniscrew removal.[286] In areas where the miniscrew had only invaded the periodontal ligament (PDL) the alveolar bone and PDL had reorganized their structures around the miniscrew and a thin cementum-like layer had formed on the implant surface where it had been in contact with the PDL.[287] 2. Severe dentine penetration resulted in replacement resorption of the root cementum with alveolar bone. 3. Pulpal penetration did not result in necrosis and there was no evidence of an inflammatory infiltrate associated with the invading miniscrew. 4. No evidence of external root resorption was seen and ankylosis only occurred in severe cases with root fracture and displacement of the fragments. The authors suggested a dramatic increase in tactile resistance during placement, indicative and diagnostic of root contact.[288, 289]

Miniscrew slippage is associated with self drilling procedures and occurs with failure to fully engage the cortical bone during placement. This may lead to the miniscrew inadvertently sliding under the mucosa along the periosteum leading to iatrogenic damage. Slippage generally occurs if the angle of insertion is too steep and it is therefore advisable to start insertion perpendicular to the long axis of the teeth for the first two to three turns. The insertion angle can then be changed once the cortical bone has been engaged.[285]

Nerve injury may occur with miniscrew placement in the maxillary palatal alveolus, mandibular buccal alveolus or retromolar region. Most nerve injuries are minor, transient and usually self corrects within six months. Knowledge of the location, size and path of the greater palatine, nasopalatine, inferior alveolar, mentalis, long buccal and lingual nerve is important to avoid potential damage to these structures.[285]

Nasal and maxillary sinus perforation may occur with miniscrew placement in the maxillary incisal, posterior dentoalveolar and zygomatic regions. Maxillofacial surgery literature suggests that small perforations (<2mm) of the maxillary sinus will routinely heal spontaneously, without complication.[290] So, even if the maxillary sinus has been perforated, the small diameter of the miniscrew will only cause a minor perforation of the sinus wall. It is therefore mostly, not necessary to remove the miniscrew and orthodontic treatment should continue as normal, with the patient being monitored for the development of sinusitis or a mucocele.

High torsional loads during placement may lead to miniscrew implants bending or fracturing. Most manufactures therefore advise insertion torque values of 10-15N. Research also suggests that miniscrews with a diameter of less than 1.2mm should not be used, as these do not have sufficient mechanical strength to resist the torsional forces created during miniscrew implantation. Self-drilling miniscrews should be inserted slowly (30rpm), with minimal pressure applied to the driver, as excessive torsional stress during placement may lead to micro fractures in the peri-implant bone and reduce the stability of the miniscrew. Cortical notching should be done prior to placement in areas of thick cortical bone. Insertion should cease once the neck reaches the periosteum as overinsertion may also lead to increased torsional stress.[291]

Stationary anchorage failure with loss of the miniscrew is also considered a complication arising from miniscrew treatment and has been previously discussed. If a miniscrew becomes loose it will not regain stability and it will need to be removed.

Miniscrew migration has recently been reported in the literature by several authors.[292, 293] Although a high percentage of miniscrews remain clinically stable during orthodontic treatment they do not stay absolutely stationary under orthodontic loading. Liou *et al.* [293] demonstrated that miniscrews loaded with 400g of force for 9 months extruded and tipped -1.0 to 1.5mm in several patients. Others have shown that this migration occurs regardless of the force magnitude that is applied. It was therefore recommended to allow a safety clearance of 2mm between the miniscrew and any anatomical structures to account for potential migration, although the practicality of this suggestion is questionable.

Minor aphthous ulcerations may develop around the miniscrew or on the adjacent buccal mucosa in contact with the miniscrew head. These ulcerations are generally self limiting and resolve within seven to ten days. Placement of a healing abutment, wax pallet or elastic separator can prevent ulceration and improve patient comfort.

Miniscrew placement in unattached mucosa, especially in the mandible, has been suggested to cause soft tissue overgrowth. Attachments that rest on the soft tissue will also likely become covered by tissue. Soft tissue overgrowth can be minimized by placement of a healing abutment, wax pallet or elastic separator. Chlorhexidene, in addition to its antibacterial properties, has also been shown to slow down epithelisation and might reduce the incidence of soft tissue overgrowth when used after miniscrew placement.[294]

Inflammation of the peri-implant tissue has been shown to increase the risk of miniscrew failure by up to 30%.[275]Twisting and bunching of the soft tissue around the miniscrew during placement should alert the operator to a possible increased risk of soft tissue inflammation at a later stage. For this reason it has been suggested by some authors that miniscrew placement be confined to keratinized attached gingiva.

Although miniscrews rely mainly on mechanical retention for stability, partial osseointegration may start to occur three weeks after placement. Depending on the degree of osseointegration present, removal of the miniscrew may be problematic. If partial osseointegration has occurred and removal is not possible without applying excessive torsional forces, it is advised to touch a heated instrument or ultrasonic scaler to the miniscrew head for a few seconds. This may cause necrosis or micro fractures of the peri-implant bone, facilitating easy screw removal two to three days later.[260]

Recent fears regarding heavy metal poisoning has prompted investigation into the systematic levels of metallic ions released from orthodontic miniscrews. Although low levels of Titanium, Aluminium and Vanadium ions were found in association with miniscrew use, the levels were well below the average intake of these elements through food and drink and did not reach toxic concentrations.[295]

5.2.7 The Aarhus Anchorage System™

The Aarhus mini-implant system was developed by Professor Birte Melsen at the University of Aarhus, Denmark and is produced by Medicon eG. It was designed with two specific indications in mind: adult patients with insufficient teeth for the establishment of conventional anchorage; patients where the reactive forces are anticipated to cause adverse side effects.[291]

The miniscrew is manufactured from a titanium alloy “wrought Titanium-6 Aluminium-4 Vanadium Eli” and consists of a body, collar, neck and head. It is manufactured in three lengths 6mm, 8mm and 11mm and the thread is cut at an angle of 11° with an asymmetrical pattern. Thread diameter is available in 1.3mm, 1.5mm and 2.0mm and the miniscrew has a cylindrical tapering form. The transmucosal collar on this miniscrew is available in a choice of either 1.5mm or 2.5mm depending on the thickness of the soft tissue. Head design is available in a choice of three; button, round or bracket head.[296]

This mini-implant is designed as a self drilling screw which is placed using the specifically designed screwdriver that covers the entire outer circumference of the miniscrew, which decreases the risk of fracture on placement and removal. The fine cutting tip makes pre-drilling unnecessary, except in areas of very dense cortical bone, like the posterior mandible, where it is advised to use a round bur to place a cortical notch prior to miniscrew placement. A recent independent clinical trial concluded that the Aarhus miniscrew achieved comparable primary stability to other, self tapping miniscrew systems.[297]

6.0 The Sydney Intrusion Spring

6.1 Introduction

Treatment of skeletal anterior open bite malocclusions through molar intrusion with skeletal anchorage devices has recently been shown to be an effective and predictable alternative to orthognathic surgery and other conventional treatment modalities. The orthodontic auxiliaries used to provide the intrusive force component however, are crude adaptations of existing auxiliaries, including NiTi coil springs, elastomeric thread or chain and rubber bands. These auxiliaries were not developed for the purpose of molar intrusion in conjunction with skeletal anchorage devices and therefore, although being adequate at accomplishing the task at hand, all have significant limitations and drawbacks. Elastomeric thread or chain requires frequent replacement and reactivation, whilst NiTi coil springs often cause significant tissue irritation and hyperplasia. No mention could be found in the literature, regarding a specifically designed intrusion auxiliary for use in conjunction with skeletal anchorage devices.

Consequently, a specifically designed spring, the Sydney Intrusion Spring (SIS), was conceived and developed by Prof MA Darendeliler and Dr R Foot at the University of Sydney; Faculty of Dentistry; Discipline of Orthodontics. The SIS is a purposely produced intrusion auxiliary, designed for maxillary dentoalveolar buccal segment intrusion, to be used in conjunction with skeletal anchorage devices like miniscrews or miniplates. It is designed to: produce a continuous active intrusion force with infrequent need for reactivation, be easy to install, reactivate and remove and be hygienic with minimal tissue irritation.

The Sydney Intrusion Spring consists of two 0.016” diameter beta-titanium closing loops containing several helices, laser welded to a 0.017x0.025” diameter beta titanium frame. The closing loops provide low continuous force production over a large range of activation, whilst the frame provides the required stiffness to resist permanent deformation of the spring during activation and placement.

6.2 Wire properties, Beta titanium wire

Beta titanium wires were introduced to the orthodontic literature by Burstone and Goldberg in 1980.[298] When pure titanium is heated to temperatures greater than 885°C its crystalline structure rearranges into a body centred cubic lattice (BCC) which changes the materials characteristics. The addition of elements such as molybdenum allows the titanium based alloy to maintain its "beta" structure at room temperature and is therefore referred to as beta stabilized titanium (β-Ti). The BCC crystalline structure imparts a unique set of properties on the wire, the likes of which had never been seen in orthodontics.

Burstone's original β-Ti consisted of 79% Titanium, 11% Molybdenum, 6% Zirconium and 4% Tin. It still forms the basis of most modern beta titanium alloys although each manufacturer subtly varies the composition of their beta titanium, the details of which is generally a closely guarded secret. The original beta titanium had a modulus of elasticity (E) of 64,811,000kPa and yield strength (YS) of 1,172,000kPa which gives it the resultant YS/E ratio of 0.018. In comparison stainless steel has a modulus of elasticity three times greater, nearly equivalent yield strength and a resultant inferior YS/E ratio of 0.011.[298, 299]

These properties give β-Ti several highly desirable characteristics for orthodontic appliance design. It has fantastic springback and may be deflected over long distances without permanent deformation. Springback for β-Ti equates to 113% that of stainless steel in a 0.017x0.025" wire size. The alloy has a stiffness of about 40% that of stainless steel and therefore produces gentler linear forces per unit activation over a substantially larger range. An interesting finding however has been that when comparing a rectangular β-Ti wire (0.017x0.025") to an equivalent stainless steel wire (0.016/0.018") it has 2.4 times greater stiffness in the occlusal plane, whilst maintaining the same stiffness in the occlusal-gingival plane.[300] It has excellent formability and may be bent, shaped and formed into intricate arrangements, such as loops, without fracture. Finally, β-Ti easily allows direct welding without significantly reducing the resilience of the material.[301-303]

6.3 Beta titanium wire welding

With the introduction of β-Ti to orthodontics it was suggested that this alloy possessed excellent welding characteristics.[298] Research has confirmed this to be the case and has shown that spot welded β-Ti joints could withstand angular and torsional moments much higher than any of those developed during clinical loading conditions.[304] With welding, the joints retained 90% of the torsional strength of the unwelded base material. The authors did however advise extra caution when welding circular to rectangular cross-section joints as these were particularly sensitive to small variations in welding voltage. The suggested characteristics of a good clinical weld are: little discolouration, little weld flash and a set down of no greater than 25% of the pre-weld thickness. A recent study on the tensile-shear strength of various welded joints concluded that β-Ti produced the most superior weld characteristics of any orthodontic material. The tensile strength for β-Ti joints was 27% greater than stainless steel. Microscopically the welded surface exhibited smooth flow with an almost intact weld surface; the weld area was small with characteristic nugget formation, it showed a wide area of demarcation indicating a gradual change from wrought to cast structure and finally displayed no observable porosities at the joint surface.[305]

Recently laser welding has become increasingly widespread in dental technology. It offers many advantages including: work efficiency leading to considerable time saving; corrosion resistant solder free joints; homogenous joint structure; high mechanical joint strength; small area affected by heat resulting in low deformation; easy connection, extension and repair of appliances; and suitability for welding of practically all dental alloys.

With laser welding, the parts to be joined are manually placed together under visual control and welded together with one or more laser pulses. The device used for the manufacture of the SIS during this research project is a Baasel Lasertec, Dentaurum desktop laser welder. It is classified as a Class 4 laser product which consists of a cylindrical neodymium-doped yttrium aluminium garnet crystal (Nd: YAG).When an intensive light is applied to the crystal it produces a light with a laser wave length of 1.06µm. It is also furnished with a stereo microscope with a crosshair which allows precise positioning of the laser pulse. The energy of the laser pulse may be manipulated by changing the setting of the pulse intensity, pulse length and/or focal area. To avoid brittleness of the weld through uncontrolled oxygen absorption, when welding titanium alloys, flooding of the welding point with Argon gas is recommended .[306]

The parameters used for the manufacture of the SIS are: Voltage= 245V, Pulse length= 3ms, Focus=0, Argon flooding of 3s prior to welding at a setting of 12ℓ per min.

6.4 Force delivery characteristics

The SIS was designed to produce a nearly linear force production. This is achieved through the closing loops welded on either side of the rigid β-Ti framework. From the literature on principles of basic biomechanics, we are aware of three fundamental approaches used to reduce the load-deflection rate of any appliance: 1.Choice of wire material. 2. Reduction in wire diameter. 3. Incorporation of loops into the appliance design. The springs of the SIS therefore consist of 016" β-Ti wire, the smallest diameter β-Ti wire commercially available, approximately 90mm of wire length and incorporate 9 helices per spring.

The limited available literature on maxillary dentoalveolar buccal segment intrusion using skeletal anchorage appear to suggest routine force levels of 200-500g per side to achieve efficient en-masse intrusion of posterior teeth. (See figure 1.) Laboratory tests suggest that the SIS is able to deliver these force levels from 5.5mm down to 0.8mm of activation. Although the force is decaying in nature, it appears to still be effective in producing efficient rates of intrusion.

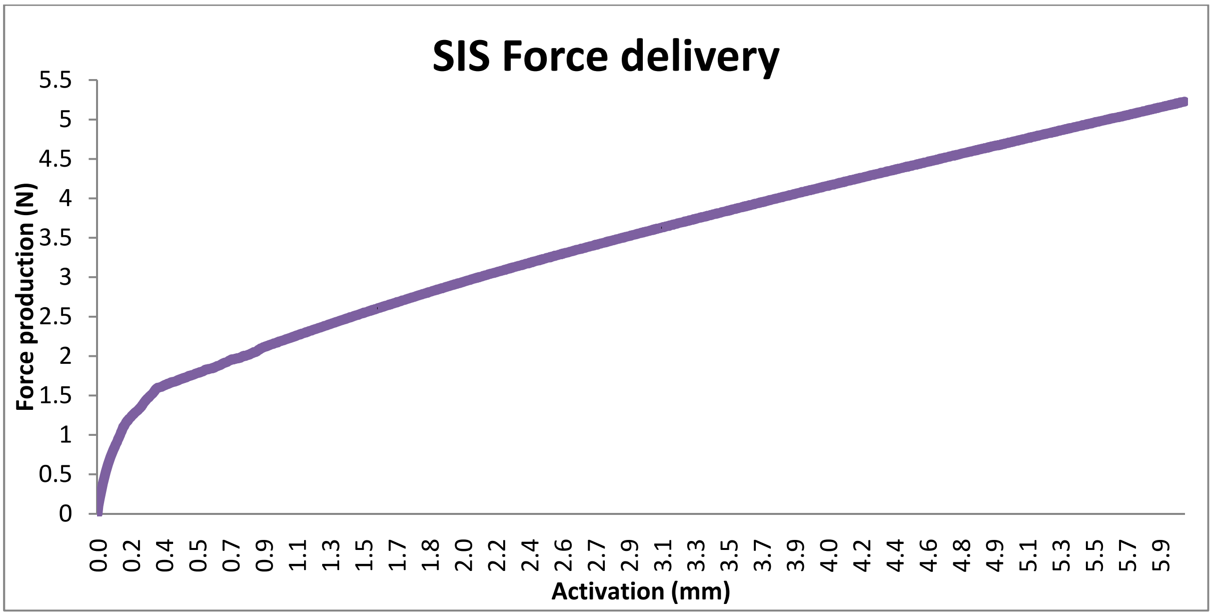

Figure 1.

7.0 Cone beam computed tomography (CBCT)

7.1 History and basic principles

Radiographs have been an essential diagnostic tool in dentistry for well over a century. The introduction of the Cephalostat by Broadbent in 1931 revolutionized the field of Orthodontics and lateral cephalograms have since become a commonly used diagnostic tool in routine clinical practice. Following its inception several authors have described techniques, norms and measurements for lateral cephalometric evaluation and interpretation. One of the major shortcomings of conventional radiographic cephelometry however has always been that it is a two dimensional display of a three dimensional object.

Three dimensional imaging in the form of computed tomography (CT) was developed by Hounsfield in 1967 and although CT has been available since 1973, its application in orthodontics has been limited due to cost and radiation dose considerations.[307] Conventional CT has evolved through five generations with the latest generation consisting of a stationary detector and an electron beam which is electronically swept along a semicircular tungsten strip anode. This creates a fan shaped beam of x-rays and the image is constructed by “stacking” multiple slices on top of one another as the x-rays rotate about the patient in a helical fashion from one end to the other.[308]

The introduction of cone-beam computed tomography (CBCT), during the early 2000’s, specifically dedicated to imaging the maxillofacial region has overcome many of the limitations of the conventional CT scanning devices. The patient image in CBCT is captured as the x-rays fall onto a two dimensional detector as it undergoes conical expansion from a single source. This difference allows a single rotation of the radiation source to capture an entire region of interest. The cone beam also produces a more focused beam and considerably less scatter radiation than conventional CT, whilst significantly reducing the x-ray tube capacity required for volumetric scanning. Research suggests that the total radiation is approximately 20% that of conventional CT and equivalent to a full mouth peri-apical radiographic exposure.[309] These innovations allow CBCT units to be less expensive and smaller. The exposure chambers are also customised for maxillofacial imaging and further reduce the amount of radiation delivered to the patient. Images from CBCT's are comparable to the conventional CT's and may be displayed as a full head view, skull view or regional components.[308] Several software developers have also started producing dedicated software for CBCT volumes, which allows volumetric analysis of hard and soft tissues. Data sets are usually exported in a Digital Imaging and Communications in Medicine (DICOM) 3-D format for image manipulation.

7.2 Radiation exposure

Radiation exposure and risk/benefit cost in orthodontics remain a contentious issue. Radiation exposure from CBCT is four times less than conventional CT and still offers comparable image quality, whilst concurrently overcoming the shortcomings of conventional radiographic views.[309] A recent study has found the NewTom 3G unit to produce the lowest amount of effective radiation dosage from any commercial available CBCT unit at 44.5µSv per 12" field of view (FOV) scan.[309] This equates to approximately 5.5 days of equivalent background radiation (3mSv/yr → 8µSv/day). In comparison an analogue panoramic radiograph produces 54µSv, full mouth series 150µSv and a transcontinental flight 139µSv.[308]

7.3 Accuracy of measurements

The recent virtual explosion of the interest in CBCT image acquisition and manipulation for use in the Orthodontic discipline has led to a concomitant flood in research on the subject. Due to the inherent magnification present in all extra-oral radiographs clinicians and researcher alike were eager to see whether CBCT would be able to produce a true 1-to-1 image-to-reality ratio. This was confirmed to be the case with all commercially available CBCT devices. Recently Lagravère demonstrated that there was no significant difference in the angular and linear measurements obtained from the NewTom 3G device compared to a coordinate measurement machine, which is considered the gold standard.[310]

Research has further concluded that linear cephalometric measurement from CBCT is accurate to within 0.3mm (1 voxel) when compared to direct calliper measurement.[311, 312] An investigation into the accuracy of dental measurements drawn from CBCT DICOM data further confirmed the accuracy of this diagnostic modality and although the CBCT volumes tended to underestimate the measurement compared to the "gold standard" of calliper measurement this difference was not significant for single measurements.[313]

Examination of factors relating to accuracy has found that head orientation in the device has no significant influence on the outcome achieved.[311] Similarly, a reduction in the number of projections per scan had no bearing on linear accuracy of the derived image.[314] This coupled with the finding that increasing the voxel size, up to a certain point, also has no influence on the final accuracy of measurements attained, is a promising development as it indicates that CBCT volumes obtained using lesser effective radiation dosages and therefore by association, lesser image quality, has no detrimental effect on the diagnostic capabilities of the apparatus.[312]

A recent study comparing the accuracy of CBCT measurements and cephalometric measurements to direct craniometric measurements has highlighted the inadequacies of conventional lateral cephalometric radiography, finding statistically significant differences across all cephalometric measurements, compared to direct craniometric measurements, with a mean difference of 5mm.[315] The authors suggest CBCT measurements to be more reliable and precise with a mean difference of only 0.1mm when compared to direct measurement methods. An earlier author also suggested that using multi-planer reconstruction (MPR) from CBCT volumes may be more precise and offer less variability in landmark location when compared to conventional lateral cephalograms.[316]

7.4 Dolphin Imaging® (V 11.0) rendered cephalograms and digital tracing

The interest in CBCT technology has also led to an associated evolution in the development and release of several third-party software programs for the visualisation, rendering, superimposition and measurement from CBCT volumes. These include programs like 3dMDvultus (3dMD), Dolphin

Imaging® (Dolphin Imaging and Management Solutions), InvivoDental™ (Anatomage Inc.) and many others. These programs employ complex algorithms to reconstruct the binary code obtained from the DICOM data sets and produce visible two and three dimensional images.[317] These include synthetic lateral cephalograms, panoramic radiographs, tomograms and three dimensional rendered volumes. These software programs further include modules for cephalometric tracing, volume sculpting and three dimensional volume superimpositions, amongst others.

The accuracy and reliability of the images produced by the software used for our research, Dolphin Imaging® V 11.0, has been validated by several studies.[317-319]

Concerns were expressed about the accuracy of the cephalometric tracing and measurement module in an earlier version of the software (V8.0)[320], but subsequent studies have found later versions to be highly accurate for both linear and angular cephalometric measurements.[321-324]

A recent study comparing the accuracy of four popular computerized cephalometric analysis programs (Dolphin Imaging, Vistadent, Nemoceph and Quick Ceph) found Dolphin Imaging to be the most accurate compared to traditional hand tracing, which they took to be the gold standard.[325] The authors further found digital cephalometric tracing to be time saving and more precise, due to the fact that once landmarks were identified data processing could be executed and completed instantly, without the limitations of measuring with a ruler and protractor.

7.5 Superimposition

Serial lateral cephalometric radiograph superimposition has long been the mainstay of orthodontic research. Superimposition allows for longitudinal assessment and interpretation of craniofacial growth or the orthopaedic/orthodontic results achieved by a treatment modality under investigation. It also allows clinicians to interpret their individual treatment results. The metallic implant method developed by Björk and co-workers[19] in the 1950's is undoubtedly the "gold standard" against which all other superimposition methods are evaluated. The implantation of metallic markers in developing children however, apart from frequently being impractical, also raises several moral and ethical considerations. Due to these considerations researchers and clinicians have to use anatomical cues to superimpose images from different time points. Growth and development research has allowed the identification of relatively stable structures, which do not change significantly during growth and may therefore be used for the purpose of superimposition. Several superimposition methods have been proposed including; the Björk structural method, Steiner, Ricketts and Broadbent methods.

Lateral cephalometric measurements and superimposition techniques are subject to considerable inherent error. These errors may be broadly classified into two groups, namely errors of projection and tracing errors. Errors of projection mainly stem from the fact that the cephalometric radiograph is a two dimensional rendering of the three dimensional facial skeleton and soft tissues. In addition, the cephalostat x-ray beams are nonparallel and emanate from a small source, producing an image that is always a distorted enlargement of the anatomical truth. Problems may also arise from the superimposition, or lack thereof, of the left and right side of the face on the projected image. Finally, projection errors may occur due to apparent shortening of the distance between points in different planes of space or radial displacement of points and structures not on the principal axis. Tracing errors stem from difficulty in the process of identifying specific anatomic landmarks on lateral cephalographs either due to their inherent position, lack of clarity due to superimposition of structures, blurring of structures due to movement during image acquisition and lack of film contrast. Measurement errors associated with the thickness of the traced line and the perceptive limits of the human eye may also add to tracing errors.[326-328] Each of the superimposition methods described in the literature falls subject to an array of shortcomings and pitfalls, due mainly to the anatomical structures or reference lines that form the basis of their superimpositions. Several reports in the literature highlight the individual idiosyncrasies of these techniques.[329-331]

Superimposition techniques using three dimensional representations derived from CBCT data volumes are still in its infancy. Early authors have attempted to achieve this on surface model rendered images through voxel by voxel superimposition on entire stable surfaces. The data is then represented through 3D colour mapped models.[332] This technique is however very cumbersome, time consuming, labour and computer intensive, with each colour mapped 3D rendering taking between 24-40 hours to complete.

Due to the relatively recent introduction of this technology, several uncertainties still exist regarding the best superimposition method to use, the three dimensional landmarks to be used for superimposition and the accuracy of superimposition from these software programs. Authors further suggest that 3D landmarks still need more precise definitions than are currently available.[316]

Due to these constraints, the reality that longitudinal growth databases are no longer allowed for ethical reason and all available growth databases are two dimensionally based, it seems that at least for the time being, 2D lateral cephalographic superimposition remains the most viable option.

CBCT rendered, synthetic cephalograms have the advantage over conventional cephalograms in the fact that the image may be manipulated to improve the quality, thereby eliminating many of the errors of projection, tracing and measurement associated with traditional superimposition methods.[317] Digital tracing and superimposition using the Dolphin Imaging® software has been validated in a recent study and results suggest that this method may be used with a high degree of accuracy and reliability for both cranial base and regional superimposition. [333]

8.0 Aims

The aim of the current study is to evaluate the efficacy of a new, purposely designed spring, the Sydney Intrusion Spring (SIS) for the intrusion of maxillary posterior teeth, in conjunction with miniscrew implants.

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10. Manuscript

Manuscript

The Sydney Intrusion Spring (SIS): An appliance for the intrusion of posterior maxillary teeth.

A Prospective Clinical Study

A condensed version of this manuscript is to be submitted for consideration and publication to the American Journal of Orthodontics and Dentofacial Orthopedics.

For the purposes of this thesis however this manuscript has been expanded and extended to provide greater detail and overview of the subject.

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10.1 Abstract

Introduction: The technology surrounding temporary skeletal anchorage devices has improved in leaps and bounds in recent history. However, no specific auxiliary exists for the intrusion of molars in conjunction with these devices and currently clinicians are forced to make do with available force delivery materials. A new a purposely produced intrusion auxiliary, the Sydney Intrusion Spring (SIS), was designed to facilitate intrusion without tissue irritation or the frequent need for reactivation.

Objective: To evaluate the effectiveness of the Sydney Intrusion Spring (SIS), an intrusion auxiliary designed for maxillary posterior dentoalveolar intrusion, in conjunction with miniscrew skeletal anchorage.

Materials and Methods: The subjects consisted of 16 adolescent patients (12 female and 4 male) with an average age of 13.1 years (range 12.2- 14.3 years). All patients were in the permanent dentition with an anterior open bite of ≥2mm. Four self drilling miniscrews were placed into the posterior maxillary buccal alveolar bone. The intrusion appliance consisted of a bonded acrylic appliance and the SIS, activated to produce an initial intrusive force of 500g. Cone beam computed tomograms (CBCT's) were taken after miniscrew placement and at the end of active intrusion. Rendered lateral cephalograms were produced and measurements were taken and compared.

Results: The study objectives were achieved in all patients in 4.91 months (range 2.5-7.75 months). The mean molar intrusion was 2.9 ± 0.8 mm ($P < .001$), resulting in over bite increase of 3.0mm ± 1.5 mm ($P < .001$). The intrusion led to a 2.6° ± 1.3° ($P < .001$) clockwise occlusal plane rotation and a 1.2° ± 1.3° ($P < .01$) counter clockwise rotation of the mandible. Dental measurements showed a significant uprighting and elongation of the incisors. The U1/SN decreased by 4.5° ± 3.3° ($P < .001$) and the U1/PP increased by 0.9 ± 0.6 mm ($P < .001$). The L1/GoGn decreased by 6.6° ± 3.8° ($P < .001$) and L1-MP increased by 1.4 ± 0.8mm ($P < .001$). There was no significant extrusion of the lower molars.

Conclusion: The Sydney Intrusion Spring is an effective appliance for the intrusion of maxillary posterior teeth, in conjunction with miniscrews.

Key words: Molar intrusion; Open bite; Skeletal anchorage; Miniscrews; Intrusion auxiliary

10.2 Introduction and Literature review

Since the start of the modern era of orthodontics, orthodontist have acknowledged anterior open bite malocclusion to be one of the most difficult malocclusions to successfully treat and maintain.[1] The term 'skeletal anterior open bite' malocclusion was first coined and subsequently described by Subtelny and Sakuda[2] They defined this malocclusion to be: "a deviation from the normal in the vertical relationship of the maxillary and mandibular dental arches leading to a definite lack of contact, in the vertical dimension, between the opposing segments of anterior teeth." The degree of lack of contact in the vertical dimension might vary from patient to patient, but must be present to be classified as an open bite.

The reported prevalence of open bite malocclusion in the published literature varies greatly. One study reports the incidence of open bite malocclusion to be 2% among fifteen year old British adolescents.[3] In the United States the NHANES III epidemiological study of 7000 children, between the ages of eight to seventeen, reports the incidence of open bite to be 6.6% among African-Americans, 2.9% among Caucasians and 2.1% among Hispanic-Americans.[4]

Discussion in the literature on the aetiology of vertical malocclusions, skeletal anterior open bites or the so called 'long face syndrome' is often distinctly seperated into the categories of genetic and environmental causes. This often leads to the so called 'Nature versus Nurture' argument. It must however be remembered that development ultimately stems from a complex interplay between several different aetiological factors during growth. These factors are often intimately related and rarely work in isolation or independently from each other.[5, 6]

Genetic factors that have been implicated in the development of a skeletal open bite malocclusion include mandibular growth, due to condylar growth direction[7, 8]; mandibular growth rotations[9-13]; underdevelopment in the middle cranial fossa height and an increased cranial base angle.[14, 15]

Research further suggests that aetiological factors arising from within the nasomaxillary complex may play a major role in the development of skeletal open bite malocclusion.[10, 11, 16-18] These studies propose that there is an excessive development of both the anterior and posterior maxillary dentoalveolar height in skeletal anterior open bite patients, which leads to backward and downward rotation of the mandible and thereby establishes and maintains the anterior open bite.

The role of environmental factors involved in the development of skeletal anterior open bite malocclusion has been studied extensively and remains controversial. Respiratory pattern, and more specifically the role of oral respiration, as an environmental factor in malocclusion, has been the subject of debate for more than a century. Several studies have shown a strong link between airway problems such as large adenoids, tonsils or nasal obstruction caused by septum deviation, large conchae or allergies.[19-23] These findings in conjunction with the characteristic 'long face' appearance, common in many patients with anterior open bite malocclusion have led to the description of 'adenoid faces'. These studies postulate that the above mentioned conditions lead to oral respiration, which in turn leads to an alteration in mandibular posture and facial growth pattern, and the development of a skeletal anterior open bite. However, opponents of such claims are critical of the research methodology used in these studies. In addition, they cite the fact that the majority of patients with skeletal anterior open malocclusion have no evidence of nasal obstruction. This does not support the notion that airway problems lead to skeletal anterior open bite malocclusions.[24-26] Therefore, it can be concluded that although oral respiration may contribute to the development of skeletal anterior open bite malocclusion, it is unlikely that it can be implicated as a frequent, sole aetiological factor.

Swallowing pattern and tongue posture are other environmental factors that have been implicated in the development of a skeletal anterior open bite malocclusion. Moyers described two types of abnormal tongue posture: the acquired protruded tongue posture associated with tonsillitis and chronic pharyngitis, which has a positive prognosis and the endogenous protracted tongue posture, which has a poor prognosis. The presence of this protracted tongue position has been verified to be present in individuals with skeletal anterior open bite malocclusion.[27] It has been postulated that this relates to airway maintenance, based on the notion that increased genioglossus muscle activity may be involved in expanding the pharyngeal diameter leading to a more patent airway from the larynx to the nose.[28, 29]

Authors have described a wide range of clinical features and cephalometric traits descriptive of skeletal anterior open bite that are common to *most* individuals. However, in any given individual with this type of skeletal dysplasia, several or only a few of the reported characteristics may be observed. Generally skeletal anterior open bite individuals present with narrow faces that are long and ovoid in appearance and may often have a convex profile. The upper third of the face is within normal limits in terms of length, but the temporal fossae may appear to be small. The middle third of the face shows a slender narrow nose, alar base and nasal apertures with a depressed nasiolabial area. In profile the middle third is often characterised by a prominent nasal dorsum and recessed nasiolabial area, although the nasiolabial angle appears normal. The lower facial third sees an overtly increased facial height, increased tooth display at rest and excessive tooth and gingival display during animation or on smiling, due to inadequate upper lip length (although the lip length is normal in terms of population norms). The lips are incompetent at rest with a large interlabial gap and a conscious effort to bring the lips together produces characteristic circum-oral muscle strain. On swallowing there is active contraction of the oro-facial musculature including severe mentalis muscle participation. In profile the lower third often displays the impression of an underdeveloped mandible which leads to a retrognathic chin appearance and lack of mental protuberance. There is marked antegonial notching and a steep angle to the lower border of the mandible. The masticatory muscles appear curved and the masseter muscle attachments are located posterior to the posterior teeth.

Intra-orally the palatal vault appears high and narrow and an extensive anterior open bite, which may extend as far as the molars, is often present. This open bite generally tends to be symmetrical. It has been suggested that dentally, the teeth are proportionally large leading to crowding or bidental proclination. The crowding has been attributed, by some, to the active pressure exerted by the lips and circum-oral musculature. Evidence also exists as to a small cuspal height on the posterior teeth, large molar height, frequent impaction of the third molars and a reduced freeway space.[14, 15] The tongue may be habitually postured forward and a simple tongue thrust exists to accomplish an anterior oral seal during swallowing. The gingival condition may also hypertrophic and desiccated due to continuous air exposure.

Cephalometrically an increase in anterior face height, mainly due to an increase in lower anterior face height, is the most commonly cited feature associated with skeletal open bite malocclusion. In general, the upper face height seems to be unaffected or somewhat reduced. This relationship leads to a reduced ratio of UFH/LFH. The posterior face height has also been found to be reduced in several studies and this in combination with the increased anterior face height leads to a reduction of the PFH/AFH ratio. Several authors also suggest: an inferiorly positioned maxillary process; maxillary posterior vertical excess with concomitant posterior inferiorly tipped palatal plane; and an increased posterior and anterior maxillary dento-alveolar height, to be major and frequent characteristics of a skeletal open bite malocclusion.[2, 6, 10-12, 14-16, 18, 30, 31] This is thought to be due to excessive vertical maxillary development. Solow[32] believes that it is compensatory or dysplastic adaption to these changes that determine the over bite, or lack thereof in individuals with skeletal open bite problems.

In the mandible an increased mandibular plane angle, large gonial angle with antegonial notching, short ramal height, backward and downward mandibular growth rotation and an increased mandibular to palatal plane angle are common features seen in skeletal open bite dysplasia. Generally the mandibular symphysis tends to be long in height, but narrow antero-posteriorly.

Schudy[12] first suggested the concept of facial divergence and hyperdivergence as the extreme seen in skeletal open bite dysplasia. Sassouni[14, 15] agreed and showed the four facial planes namely optic, palatal, occlusal and mandibular are highly divergent and intersect close to the face in these individuals. Furthermore it has been shown that the palatal plane and occlusal plane are increased relative to Sella-nasion and that two distinct occlusal planes exist (maxillary, which is tipped up and mandibular, which is tipped down).[33, 34]

Several conventional treatment methods have traditionally been proposed to treat these patients. Extra-oral traction like high pull, either to molar tubes[35, 36], maxillary splint[37, 38]or functional appliance[39, 40], with force magnitudes ranging anywhere from 300-1500g and application times ranging from 10-24 hours per day have been proposed. The treatment outcomes varied from purely dental, with intrusion or no extrusion of the maxillary molars, lingual tipping and extrusion of incisors and concomitant extrusion of the mandibular molars to highly significant vertical orthopaedic restraint of the maxillary position, maxillary posterior dental intrusion, no concomitant extrusion of the mandibular molars and forward autorotation of the mandible.[35-38, 41-49] Vertical chin cup therapy is another extra-oral approach employed and may also be used alone, with fixed orthodontic appliances or in conjunction with functional appliances[50] to address vertical control of the mandible during skeletal open bite treatment.

Removable functional orthopaedic appliances like the Functional Regulator-4 (FR-4) by Fränkel[51] and modified Bionator/Activator appliance[52] have been described in the literature for the treatment of skeletal anterior open bite malocclusion. Recent systematic reviews of these studies however have been highly critical of their methodology and conclusions, suggesting that their findings should be viewed with caution.[53, 54]

The use of orthodontic appliances, especially in the treatment of preadolescent and adolescent patients, has had widespread popularity. Passive posterior bite blocks showed great promise in animal models,[55, 56] but failed to translate into consistent success in humans, as Kiliaridis[57] found the main improvement in over bite with passive posterior bite blocks to occur mainly within the first weeks followed by a plateau period. Magnetic bite block appliances like the Active Vertical Corrector (AVC)[58] and MAD IV appliance[59] were suggested to overcome the limitations of passive appliances. Of concern however, are the shearing forces created by the magnets in repulsion. Several authors have indicated that unilateral crossbite or full scissor bite is a frequent and consistent side effect observed with this kind of treatment modality.[57, 60] Animal models have even been able to demonstrate the development of a true skeletal asymmetry in the transverse dimension due to these forces.[61]

The Multiloop Edgewise Archwire technique (MEAW) developed by Kim[62] endeavours to upright and intrude the mesially inclined posterior teeth after any mechanical blockages have been removed. Kim believes mesial inclination of the posterior teeth to be a major obstacle in open bite correction, especially in high angle patients. A cephalometric study comparing the effects of MEAW therapy to controls found an increase in the upper and lower anterior dentoalveolar height and decrease in the lower posterior dentoalveolar height, but not the upper posterior height. The entire dentition was moved distally and the interincisal angle was decreased. The open bite was therefore corrected by changing the occlusal plane and distally uprighting the teeth. MEAW therapy however had no significant impact on the skeletal pattern.[63]

The use of fixed appliances in conjunction with anterior vertical elastics to extrude the incisors and achieve a positive over bite has long been a mainstay of conventional open bite treatment.[2, 12, 33] Nevertheless, the use of anterior elastics and the associated elongation of the incisors is often extremely detrimental to the facial and smile aesthetics in patients with skeletal anterior open bite dysplasia, where frequently the anterior dentoalveolar height is already excessive and the patient shows excessive gingiva on smiling. Investigation has also shown this method to be associated with a high relapse potential.[64]

Extraction treatment, with removal of first premolars, has also frequently been employed in the treatment of skeletal anterior open bite malocclusion, even when crowding is deemed to be mild.[6, 10, 12] It was thought that extraction of the first premolars, with protraction of the first molars towards the front of the palatomandibular wedge, may lead to an anterior rotation of the mandible, thereby simultaneously improving the vertical over bite relationship and the frequently observed Class II relationship.[65] Closer scrutiny has however found no differences in the molar heights, anterior facial heights and mandibular plane angle between extraction and non extraction subjects. These findings suggest that the lack of mandibular rotation was due to compensatory extrusion of the molars during treatment and that correction of the anterior open bite was therefore solely achieved by lingual tipping and extrusion of the incisors.[66-68]

It has been proposed that 90% of patients with skeletal anterior open dysplasia are best treated by a combination of orthodontic and orthognathic surgical procedures.[69] Most often the maxilla is the principal focus of surgery in skeletal open bite dysplasia as the vertical development of the nasomaxillary complex is nearly always excessive in these individuals.[70] Superior maxillary surgical repositioning can be achieved, either through a total (Le Fort I) or segmental maxillary osteotomy. Surgical treatment however is highly invasive, costly, has inherent risk involved and cannot be undertaken until vertical growth has been completed.

With the advent of orthodontic temporary skeletal anchorage devices (TSAD's)[71-74] orthodontists for the first time have had a reliable source of non-compliance based stationary anchorage. This first published report in the literature on molar intrusion in humans, using skeletal anchorage, was by Umemori *et al.* in 1999.[75] The intrusion was achieved using the Skeletal Anchorage System (SAS) pioneered in Japan. They demonstrated several cases in which the lower molars were intruded by 3mm to 5mm, using 500g of force per side. Intrusion was accomplished in 5 to 9 months with no side effects to the rest of the dentition. Following on from this Erverdi *et al.*[76] successfully demonstrated the intrusion of maxillary molars in humans, using zygomatic buttress skeletal anchorage. With the use of miniscrews gaining more widespread acceptance and becoming part of routine clinical practice in the new millennium, Paik *et al.* [77] were the first to demonstrate the use of miniscrews only, in the treatment of a skeletal anterior open bite dysplasia by molar intrusion.

Subsequently, several studies[78-82] have shown maxillary molar intrusion, using skeletal anchorage, to be a viable and reliable treatment modality for the treatment of skeletal anterior open bite malocclusion.

The orthodontic auxiliaries used to provide the intrusive force component however, are crude adaptations of existing auxiliaries, including NiTi coil springs, elastomeric thread or chain and rubber bands. These auxiliaries were not developed for the purpose of molar intrusion in conjunction with skeletal anchorage devices and therefore, although being adequate at accomplishing the task at hand, all have significant limitations and drawbacks. Elastomeric thread or chain requires frequent replacement and reactivation, whilst NiTi coil springs often cause significant tissue irritation and hyperplasia. No mention could be found in the literature, regarding a specifically designed intrusion auxiliary for use in conjunction with skeletal anchorage devices.

Consequently, a specifically designed spring, the Sydney Intrusion Spring (SIS), was conceived and developed by Prof MA Darendeliler and Dr R Foot at the University of Sydney; Faculty of Dentistry; Discipline of Orthodontics. The SIS is a purposely created intrusion auxiliary, designed for maxillary dentoalveolar buccal segment intrusion, to be used in conjunction with skeletal anchorage devices like miniscrews or miniplates. After testing the force delivery characteristics and magnitude of several different spring designs the current version, delivering an initial force of 500g, was created. It is designed to: produce a continuous active intrusion force with infrequent need for reactivation, be easy to install, reactivate and remove and be hygienic with minimal tissue irritation.

For the purposes of this study, the null hypothesis assumed that posterior dentoalveolar intrusion using skeletal anchorage and the SIS provided no statistically significant changes in the cephalometric measurements of the subjects studied. The aim of this prospective study is to evaluate the clinical use as well as the dental and skeletal effects of the Sydney Intrusion Spring.

10.3 Materials and Methods

Patient selection

The subjects selected for this study consisted of 16 adolescent patients (12 female and 4 male) with an average age of 13.1 years (range 12.2- 14.3 years). The criteria for inclusion in the study were: patients in the permanent dentition with an anterior open bite between the upper and lower incisors of 2mm or greater; adequate incisor display on smiling and at rest; an increased lower anterior facial height; convex profile; no severe maxillary posterior crowding or rotated teeth; no current habits, such as digit sucking or tongue thrust; no previous orthodontic treatment, trauma and no dental or congenital anomalies; good oral hygiene and no periodontal disease.

The subjects were recruited from those that had been referred to the Department of Orthodontics at the Sydney Dental Hospital, Sydney, Australia for orthodontic treatment. Ethics approval was obtained from the Human Research Ethics Committee, SSWAHS No. X10-0070 & HREC/10/RPAH/126. All patients and their parents were informed of the study protocol, the advantages of intrusion treatment using miniscrews and the possible complications that might arise from said treatment. Informed consent was then obtained for all subjects.

Appliance components and design

The intrusion appliance used for this study consisted of three main parts, the Sydney Intrusion Spring (SIS), a bonded acrylic maxillary expander and four miniscrews.

The Sydney Intrusion Spring (SIS) consists of two 0.016” diameter beta titanium closing loops containing several helices, laser welded to a 0.017x0.025” diameter beta titanium frame. The closing loops provide low continuous force production over a large range of activation, whilst the frame provides the required stiffness to resist permanent deformation of the spring during activation and placement.

The bonded acrylic appliance employed was based on a design previously used successfully in the department. It consisted of two shallow acrylic bite blocks with an internal wire frame, covering all teeth to be intruded (premolars and molars) and constructed to produce minimal bite opening.[83] The bite blocks were connected by a 7mm hyrax expansion (Dentaurum, Ispringen, Germany) screw which was bent to allow sufficient palatal clearance for intrusion.[79] The buccal surface of the bite blocks further incorporated two self ligating brackets (0.022" slot, Speed™, Strite Industries, Cambridge, Ontario, Canada) on each side, welded to the internal framework. The brackets were positioned to align with the miniscrews and allow a vertical clearance of 12mm between the slot on the miniscrew and the slot on the bracket **(Figure 1).**

Miniscrew placement

After the administration of local infiltration anaesthesia the placement site was cleaned using a chlorhexidene 0.12% saturated gauze swab. Following this, the lateral end of a probe was used at the implant site to indent the outline of the roots into the soft tissue, thereby delineating the mesial and distal borders of each placement site, in accordance with the Cope Placement Protocol™.[84]

Four self drilling miniscrews (Aarhus™, Medicon eG, American Orthodontics; diameter, 1.5mm; length, 6mm) were then placed into the maxillary buccal alveolar bone, through the gingiva. The miniscrews were placed between the upper first and second premolar and the second and first molar on both the left and right side of the maxilla. All miniscrews were placed by a single operator (R.F.). Alginate impressions were then taken of the upper and lower arches, including the miniscrews. Patients were requested to rinse with a 2mg/ml chlorhexidene mouthwash (Savacol, Alcohol Free, Colgate) twice a day for ten days after miniscrew placement.

Appliance placement and loading

All bonded appliances were checked for fit and cemented using glass ionomer cement. The SIS was then placed bilaterally and activated to produce an initial intrusive force of approximately 500g **(Figure 2).** Loading of the miniscrews was initiated immediately after placement (<48 Hours) and continued until sufficient intrusion had been achieved. Rapid maxillary expansion was also prescribed, at a rate of 0.25mm per day, until 30% overexpansion had been achieved. Subjects were seen at 4-week intervals to observe progress and the springs were reactivated when the force delivery approached 200g.

Treatment was continued and sufficient intrusion was deemed to be achieved once the over bite, as measured between the upper and lower incisor tips, minus the bite blocks, reached 2mm **(Figure 3).**

After the completion of treatment the intrusion appliance was removed, records were taken and a transpalatal arch (TPA) and partial fixed appliance were placed for retention. The intrusion achieved was maintained through wire fixation between the molar bands on the TPA and the miniscrews (**Figure 4).** Patients were then referred to a staff specialist for the continuation full fixed appliance treatment, which will be the subject of an ongoing study.

Data analysis

Cone beam computed tomograms (CBCT's) were taken immediately after miniscrew placement at T1 and at the end of active intrusion, after appliance removal, at T2. The tomograms were acquired using a NewTom 3G (QR, Verona, Italy) with a 12" Field of view (FOV). The DICOM data obtained from the CBCT's were processed to produce rendered lateral cephalograms, using the Dolphin Imaging system (version 11.0, Dolphin Imaging & Management Systems, Chatsworth, California).[85, 86] All cephalograms were digitally traced by one investigator (R.F) using the Dolphin software. Twenty three conventional cephalometric measurements were included, consisting of twelve angular and eleven linear measurements[78-80, 82] **(Figure 5a & b).** In addition four linear vertical measurements were taken from the more recently described stable basicranial line (SBL)[87-89] **(Figure 5c).** These were: SBL-U6, SBL-U1, SBL-PP and SBL-Gn. To negate any possible contribution of relative intrusion, through growth, a further measurement from U6 to PP was done by transferring the PP from the T1 to T2 radiograph by regional maxillary superimposition.

An error measurement study was done to evaluate the intra-examiner reliability, one month after the initial tracings. In this study, the method error did not exceed 0.3 mm for the linear variables and 0.4° for the angular variables.

Statistical analysis of the cephalometric study data was performed with the Statistical Package for the Social Sciences (SPPS, ver. 17.0, SPSS Inc., Chicago, Illinois) was used for descriptive statistical analysis, using paired-sample *t*-tests.

10.4 Results

One miniscrew was lost from Subject 1 and this subject was subsequently removed from the study. The final subject population therefore consisted of 11 females and 4 males with an average pretreatment open bite of 2.6mm (range 2.1 – 6mm). The study objectives were achieved in all patients and the average intrusion time was 4.91 months (range 2.5-7.75 months).

The data from the pretreatment and post intrusion lateral cephalograms, local superimpositions as well as results of the paired *t*-test are summarized in **Table 1**. Statistically significant changes were observed in several key cephalometric parameters.

The main study objective, posterior dental intrusion, was shown to be effectively achieved, as is reflected by the parameters measuring this outcome. The U6-PP decreased by 2.9 ± 0.8 mm ($P < .001$), SBL-U6 reduced by 3.2 ± 0.6 mm ($P < .001$) and local superimposition showed a reduction of 2.7 ± 0.7 mm ($P < .001$) to the maxillary reference line. This translated to an average over bite increase of 3.0mm ± 1.5 mm ($P < .001$). This observed dental intrusion proceeded at an average rate of 0.59 mm/month.

There was significant uprighting and elongation of the upper and lower incisors. The U1/SN was statistically significantly decreased by 4.5° ± 3.3° ($P < .001$) and the U1-PP measurement increased by 0.9 ± 0.6 mm ($P < .001$). The lower incisors uprighted by 6.6° ± 3.8° ($P < .001$) and showed an average elongation of 1.4 ± 0.8mm ($P < .001$) to the mandibular plane. These changes led to an average increase in the interincisal angle of 12.2° ± 5.1° ($P < .001$).

The posterior dental intrusion caused a clockwise rotation of the upper occlusal plane, leading to an increase in angulation of Occ Pl/SN of 2.6° ± 1.3° ($P < .001$). The intrusion also caused a counter clockwise autorotation of the mandible. This lead to decrease in SN/MP of 1.2° ± 1.3° ($P < .01$), a decrease of 0.9° ± 1.2° ($P < .05$) in FMA and a 1.01 ± 1.44 mm ($P < .05$) decrease in SBL-Gn. These changes translated to a decrease in lower anterior facial height of 0.9 ± 1.mm ($P < .01$).

There was no significant increase in the measurement of the lower molars to the mandibular plane or SBL to the palatal plane. Midfacial skeletal parameters also remained stable.

10.5 Discussion

The literature suggests an inferiorly positioned maxillary process; maxillary posterior vertical excess, with concomitant posterior, inferiorly tipped palatal plane; and an increased posterior and anterior maxillary dento-alveolar height, to be major and frequent characteristics of individuals with a skeletal open bite malocclusion.[2, 6, 10-12, 14-16, 18, 30, 31] The treatment objective for these patients should therefore be intrusion of the maxillary posterior teeth, to address the morphological discrepancies present with this malocclusion and to improve facial aesthetics. Reitan and Rygh further suggest intruding teeth to be a more stable treatment modality, compared to extruding teeth.[90]

Several conventional treatment modalities such as headgear[35, 36], bite blocks that are passive[91] or magnetic[58, 60, 92], spring loaded appliances[93, 94] and removable orthodontic appliances[95] have been suggested for the intrusion posterior teeth. These appliances however all had significant drawbacks and /or side effects.[57, 60, 91]

The intrusion of posterior teeth, using skeletal anchorage was first shown to be possible by Southard *et al.* [96] in mongrel dogs, using osseointegrated implants. With the introduction of miniscrews Ohmae *et al.* [97] subsequently demonstrated the possibility of using miniscrews for the intrusion of mandibular third premolar teeth in beagle dogs. Following the report on molar intrusion in human subjects by Umemori *et al.*[75], there has been several studies that have shown molar intrusion, using temporary skeletal anchorage devices (TSAD), to be a viable treatment modality.[78-82]

However, no firm evidence exists in the literature regarding the optimal force levels for maxillary dentoalveolar intrusion.[98] The proponents of extra oral traction, in the form of headgear, advocate relatively high force magnitudes ranging anywhere from 300-1500g of force. Most however use forces in the range of 400-600g. In terms of traditional intraoral tooth borne mechanics, Burstone[99] suggested 20g of intrusive force for incisors and 50g for canines, whilst Proffit[100] advocates 10-20g of continuous intrusive force. Kalra *et al.* [60] applied 90g of force to intrude molars in children compared to Melson and Fiorelli[101] who suggested 50g of force for molar intrusion in adults. With the advent of skeletal anchorage, force systems could be altered and increased without concern for unwanted side effects in the reactive unit and Büchter[102] found miniscrews to remain clinically stable at force levels up to 900g. Using skeletal anchorage, the suggested intrusive force level for single maxillary molars, from literature, appears to be 100-200g.[103] Kato and Kato[104] however found 100g of force to be insufficient for en-masse molar intrusion, but smooth progressive intrusion was achieved when the force levels where increased to 300g per side. The literature therefore seems to suggest optimal force levels of 200-500g for en-masse molar intrusion using skeletal anchorage.[78-82]

Consequently the Sydney Intrusion Spring (SIS), a purposely designed intrusion auxiliary, was developed to produce clinically significant, efficient en-masse intrusion of posterior teeth. Laboratory tests suggest that the SIS is able to deliver these suggested force levels of 500g – 200g in a curvilinear fashion from an activation of 5.5 mm down to 0.8 mm **(Figure 6).**

The present study is the first that we are aware of to investigate the treatment of skeletal anterior open bite malocclusion, through molar intrusion with TSAD's, in an adolescent sample group. Our results, which indicate an average of 2.9mm molar intrusion and 3.0mm increase in overbite, however compares favourably to the results of conventional open bite treatment in adolescents.

Firouz *et al.*[47] investigated the effect of high pull headgear in 12 patients with an anterior open bite of at least 2mm. The headgear was worn for 12 hours per day for 6 months and produced an average of 0.54 mm intrusion of the maxillary molars. Orton *et al.*[38] demonstrated 0.72 mm of molar intrusion when using a maxillary intrusion splint and near vertical pull headgear with 500g of force per side, for 14 hours per day. Recently Abudallatif and Keles[105] described the use of an acrylic cap splint expander and occipital headgear to cause intrusion of the maxillary posterior teeth and a clockwise moment on the maxillary dento-alveolar complex. The headgear was activated to produce a force of 500g per side and was worn for 14-16 hours per day for 6 months. Results suggested a clockwise rotation of the maxillary dentition, reduction in mandibular plane angle; maxillary molar intrusion of 2.81mm and an over bite increase of 3.75mm.

A study by Kiliaridis *et al.*[57] comparing passive posterior bite blocks to posterior repelling splints suggest that passive blocks are able to produce a vertical over bite correction of 1.5 – 3.0 mm in younger individuals, but that the main improvement seems to occur in the first weeks, followed by a 'plateau' period. No figure was given for the amount of molar intrusion achieved.

Investigation into a fixed magnetic appliance, producing an intrusive force of 1080g to the upper and lower posterior dentition, by Kalra *et al.*[60] found an average of 1.6mm maxillary molar intrusion, 3.8mm increase in over bite and a mandibular plane angle decrease of 1.3° after 4 months of treatment. However, a 4 month follow up period saw 1.8mm of eruption of the maxillary molars. Meral and Yüksel[59] studying the MAD IV appliance, a removable appliance consisting of anterior attracting and posterior repelling magnets, producing a reciprocal force of 300g, found no significant maxillary molar movement, but 0.75mm of mandibular molar intrusion with the use of this appliance.

Recently, Gurton *et al.*[95] investigated the use of a removable acrylic appliance, the Molar Intruder, for the treatment of anterior open bite malocclusions in growing patients. The appliance consisted of a removable maxillary appliance with Adams clasps on the maxillary premolars and molar intrusion springs on the upper and lower molars, bent from 0.7mm stainless steel wire. The intrusion springs were activated to produce a force of 110g if only the first molars were present or a force of 180g if both first and second molars were present. Results showed a mean maxillary molar intrusion of 1.86mm, a mandibular molar intrusion of 1.04mm and an over bite increase of 4mm. When the first and second molars were included the average intrusion was nearly halved.

The literature on maxillary molar intrusion using TSAD's consists primarily of individual case reports and the patients were all adults with long standing anterior open bite malocclusion, many of whom had refused conventional combined orthodontic-orthognathic surgical treatment.[106-108]

Sherwood *et al.*[81] were the first to undertake a prospective pilot study, using titanium miniplates, to intrude maxillary molars. Their results suggest a mean molar intrusion of 1.99mm, over bite increase of 3.62mm and a mandibular plane decrease of 2.62°, in 5.5 months of treatment.

A pilot study by Erverdi *et al.* [78] employed similar means of skeletal anchorage, consisting of bilateral zygomatic buttress titanium miniplates, loaded 4-7days post-operatively. The 10 subjects participating in the study were aged between 17-23 years and had a mean open bite of 0.6mm (± 2.27mm). The intrusive force of 200g per side was applied via 9mm closed NiTi coil springs. The resultant maxillary molar intrusion was on average 2.6mm with an over bite increase of 3.7mm and mandibular closing rotation of 1.7°. Active intrusion time averaged 5.1months. They further observed elongation of both the upper and lower incisors by 1.1mm, 9.6° retroclination of the upper incisors and a 3.1° increase in the occlusal plane angle.

Kuroda *et al.* [80] in their prospective study of 10 adult female subjects (mean age 21.6 years) with an anterior open bite malocclusion of 5.2mm on average (±1.8mm), by means of either SAS miniplates or titanium miniscrews; showed an average of 3.6mm of molar intrusion, 6.8mm over bite increase, 3.3° reduction in mandibular plane and no elongation of the incisors. These results were achieved in 7 months of active intrusion.

A subsequent study on molar intrusion by Erverdi *et al.* [79] evaluated the maxillary posterior dentoalveolar segment intrusion in 11 anterior open bite subjects with a mean age of 19.5 years. For this study the authors used two 9mm NiTi coil springs on each side, increasing the intrusive force to 400g per side. Results suggest a mean molar intrusion of 3.6mm, an over bite increase of 5.1mm and

3.0° reduction in facial convexity. No significant changes were observed in the vertical or angular incisor position. The average treatment time was 9.6 months.

Xun *et al.* [82] employed both maxillary palatal and mandibular buccal miniscrews to evaluate the posterior dentoalveolar intrusion in 12 subjects (mean age 18.7 years) with a mean pretreatment open bite of 2.2mm. Results suggest that the maxillary first molars were intruded on average 1.8mm, mandibular molars 1.2mm, mandibular plane angle decreased by 2.3° and the over bite increased by 4.2mm in 6.8 months. They further report 1.3mm of extrusion of both the upper and lower incisors; 5.0° retroclination of the upper and 1.4° of the lower incisors; and a 4.4° increase in the occlusal plane to SN.

Data from the current study suggests intrusion of 2.9mm at the maxillary first molars, an over bite increase of 3.0mm, mandibular plane decrease of 1.2° and an occlusal plane increase of 2.6°. These results compare favourably to those found by several other studies[78, 81, 82], but is less than that found by Erverdi *et al.(2007)*[79] and Kuroda *et al.*[80] The greater intrusion found by these studies might be explained by the fact that the their subject group started with larger pretreatment open bites (Kuroda *et al.*[80] mean pretreatment open bite, 5.2mm) and therefore required significantly greater intrusion than our sample, who had a average pretreatment open bite of 2.6mm.

The appliance used in the present study applied no direct mechanics to the anterior teeth. The treatment intervention did however result in significant passive uprighting and elongation of the incisors. Anterior occlusal interference, with a posterior open bite, was therefore a frequent finding on appliance removal **(Figure 7).** These frequently observed anterior occlusal interferences is a possible explanation for the reduced over bite correction; decrease in mandibular plane angle, facial convexity and lower anterior facial height found in the present data, compared to similar studies. Subjects from this study, on initial intrusion, are currently the topic of a further ongoing study aimed at comprehensive full fixed orthodontic appliance therapy of their malocclusion. It is anticipated that results from this study will show a continued improvement in the skeletal cephalometric measurements.

The significant elongation and uprighting of the upper and lower incisors, with the upper incisors extruding by 0.9mm and retroclining by 4.5°, whilst the lower incisors extruded by 1.4mm and uprighted by 6.6°, is in concurrence with the results found by Erverdi *et al. (2004)*[78] and Xun *et al.* [82]

The active intrusion time in the present study is comparable to that of Sherwood *et al.*[81] and Erverdi *et al. (2004)*[78], but with greater dentoalveolar intrusion achieved and significantly shorter than several other studies.[79, 80, 82]

Due to the fact that our subject population consist of growing individuals, the contribution of relative intrusion, through vertical maxillary growth, to the total intrusion achieved could not be disregarded. Therefore, additional measurement using regional superimposition to transfer the maxillary plane was done **(Figure 8).** Measurement from SBL to palatal plane was also done to further verify the prior. These parameters indicated that there had been virtually no vertical maxillary growth during the treatment intervention period. Relative intrusion has therefore not significantly contributed to the amount of intrusion achieved, as measured to the palatal plane. This may attributed to the relatively brief duration of the treatment intervention.

The presence of the SIS was well tolerated by all subjects. Subjects also reported little difficulty in adaption and maintenance of the appliance. Subjective clinical observation suggests that the SIS resulted in little or no tissue irritation and no gingival overgrowth, even in the presence of poor oral hygiene **(Figure 9).**

Although several previous studies employed titanium miniplate anchorage, self drilling orthodontic miniscrews with a diameter of 1.5mm and 6mm in length were used in the current study. We believe that these devices are reliable and effective sources of anchorage for molar intrusion. Furthermore, they offer a simple insertion and explanation technique, are relatively affordable and require very little instrumentation for placement and removal. Compared to miniplates this treatment generally requires a very atraumatic surgical procedure with greater patient comfort and better postoperative sequalae. A recent study comparing miniscrews to miniplates, by Kuroda *et al.*[109] found that only 50% of the miniscrew subjects reported pain one hour post-operatively, compared to 100% of the miniplates subjects. Pain assessment using the Visual Analogue Scale (VAS) put the pain intensity associated with miniscrews at 19.5, as opposed to 66.4 with miniplates (VAS of pain after 1 day of orthodontic treatment scored 40-50). One day after surgery only 10% of miniscrew subjects still reported pain, with the figure dropping to 0% by seven days. In comparison, 30% of miniplate subjects reported pain on day seven and 10% still reported pain by day fourteen. Miniplates were also more often associated with swelling, speech difficulty, problems with chewing and difficulty in tooth brushing.[109] The cumulative success rates of miniscrew implants average 84% and they are therefore able to offer predictable and efficient treatment outcomes. The ability for orthodontic clinicians to place the miniscrews themselves also presents greater flexibility and more precise control over biomechanics.[110-112]

Interestingly, several studies suggest increased failure rates of miniscrews in younger adolescent patients.[113-115] Others further suggest higher than average failure rates in individuals with a hyperdivergent open bite facial pattern, increased mandibular plane angle, high Frankfurt horizontal plane and low upper gonial. These factors have mainly been related to a decreased cortical bone thickness in younger patients and individuals with a hyperdivergent skeletal open bite facial pattern.[116-118] These findings however have not been supported by our current data, with only 1 out of the 64 miniscrews placed during the study, failing.

Most research pertaining to the adverse effects of molar intrusion has been gained from animal models. With regards to the periodontal effects of intruding teeth, conflicting evidence exists.[119] Authors however agree that good oral hygiene is critically important for the maintenance of periodontal attachments and that in the absence of good oral hygiene, intrusion of teeth would ultimately lead to periodontal breakdown and marginal bone loss.[120] Research into the neurovascular changes associated with dentoalveolar intrusion appear to suggest that these changes transient in nature, and that after a sufficient retention period, angiogenesis occurs at the apical foramen, the circulatory pattern is restored and reparative changes occur within the pulp, resulting in no long term detrimental neurovascular effects on the dental pulp.[121] Traditionally, intrusion is proposed to be a type of tooth movement highly correlated with an increased risk of orthodontically induced inflammatory root resorption (OIIRR). Several animal studies on molar intrusion using skeletal anchorage however, have not found an increase in OIIRR, associated with this treatment modality.[122-125] A recent retrospective radiographic study compared OIIRR in open bite cases treated by skeletal anchorage molar intrusion versus matched controls treated with fixed orthodontic appliance and no intrusive mechanics. The authors found a mean difference of 0.58mm in molar root resorption between the two groups which, although statistically significant, was found to be clinically irrelevant.[126] Concerns regarding anatomical structures intimately related to the tooth roots, like the maxillary sinus, during maxillary dentoalveolar intrusion also appear to be unfounded. Recent research has shown that even when maxillary teeth were purposely intruded to a point where they encroached on the maxillary sinus, the nasal floor remodelled in an apical direction to maintain its integrity and prevented breaching of the nasal mucosa.[124]

Molar intrusion using skeletal anchorage is a relatively new treatment modality; hence, very limited literature exists on the stability of the intrusion results achieved. Sugawara *et al.* [127] were the first to report on treatment stability, suggesting a relapse rate of 30% for mandibular molar intrusion one year after treatment. More recently reports on maxillary molar intrusion relapse have been discussed in the literature with Heravi *et al.* [128] reporting a relapse rate of 19% after 2.1 mm of initial intrusion, 6 months into retention. Lee and Park[129] reported nearly half that rate, with only 10.4% relapse of the initial maxillary molar intrusion one year after treatment.

Baek *et al.* [130] recently were the first to publish an investigation on the long-term stability of maxillary posterior dentoalveolar segment intrusion using skeletal anchorage devices. Their report describes the post treatment changes in nine adult patients (average age 23.7 years), three years after treatment. On average the maxillary molars were intruded by 2.39mm and experienced eruption of 0.45mm by the three year follow up period. This equated to a relapse rate of 22.9%, with authors further reporting that 80% of the total relapse occurred in the first year of retention. In parallel with this, the over bite increased by a mean of 5.56mm during treatment, but only relapsed by 1.2mm in three years.

10.6 Conclusion

The Sydney Intrusion Spring (SIS), a purposely designed intrusion auxiliary, is an effective appliance for the intrusion of maxillary posterior teeth, used in conjunction with miniscrew TSAD's.

The appliance is able to achieve clinically significant intrusion over a large range of activation, with minimal maintenance and requirement for reactivation.

The presence of the appliance is well tolerated by patients and resulted in minimal tissue irritation and no gingival overgrowth.

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Ignorance more frequently begets confidence than does knowledge: it is those who know little, and not those who know much, who so positively assert that this or that problem will never be solved by science.

~Charles Darwin~

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10.9 List of Figures

Figure 1- Sydney Intrusion Spring (SIS) and bonded acrylic appliance

a) Activated appliance

b) Appliance placed, not activated

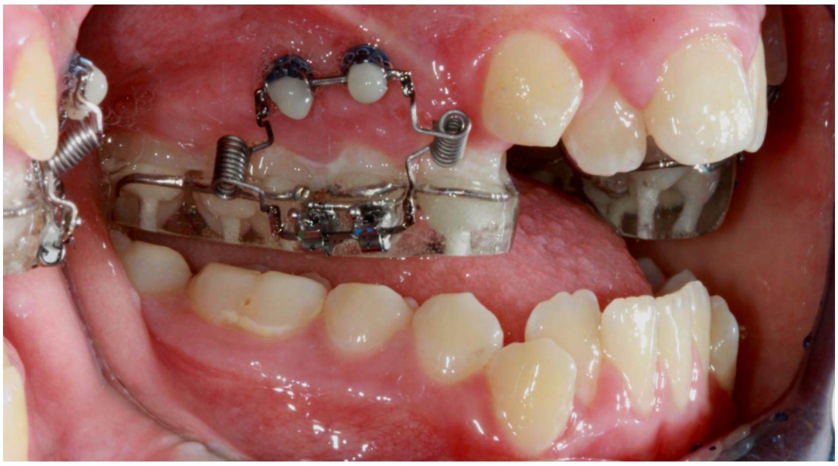
Figure 2- Patient KB at appliance placement

A) Extra oral photographs

B) Intra oral photographs

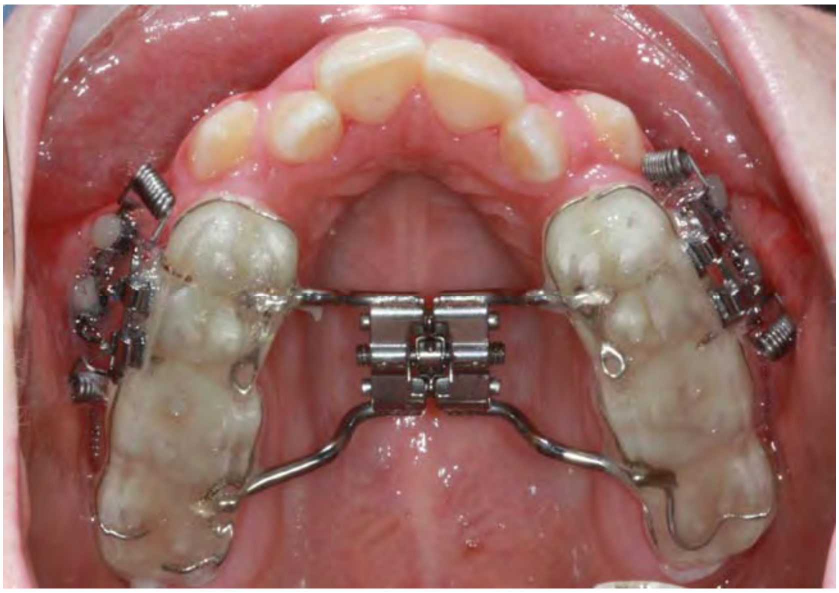
C) Appliance placed and activated

Frontal View



Intra oral Right

Intra oral Left



Upper Occlusal

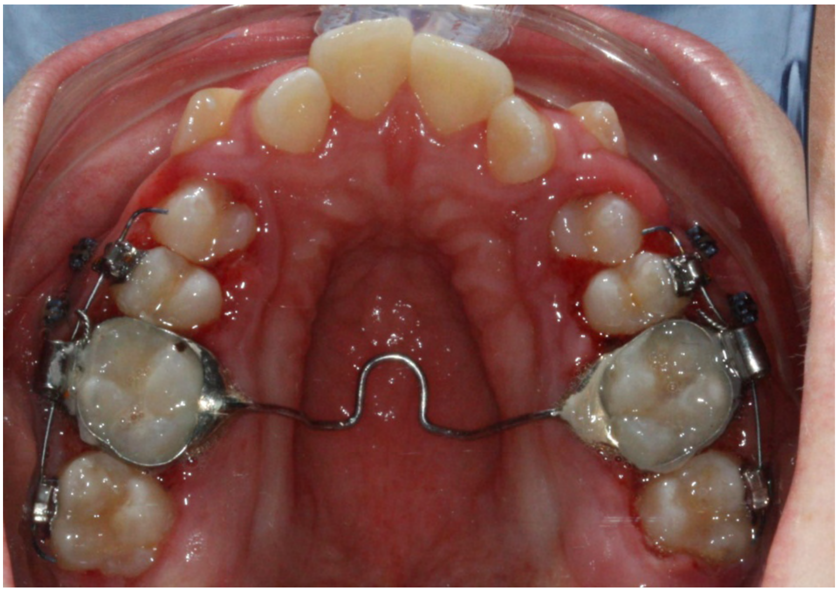
Lower Occlusal

Figure 3- Subject KB at the conclusion of active intrusion

A) Extra oral photographs

B) Intra oral photographs

Figure 4- Subject KB after appliance removal and the placement of retention appliances

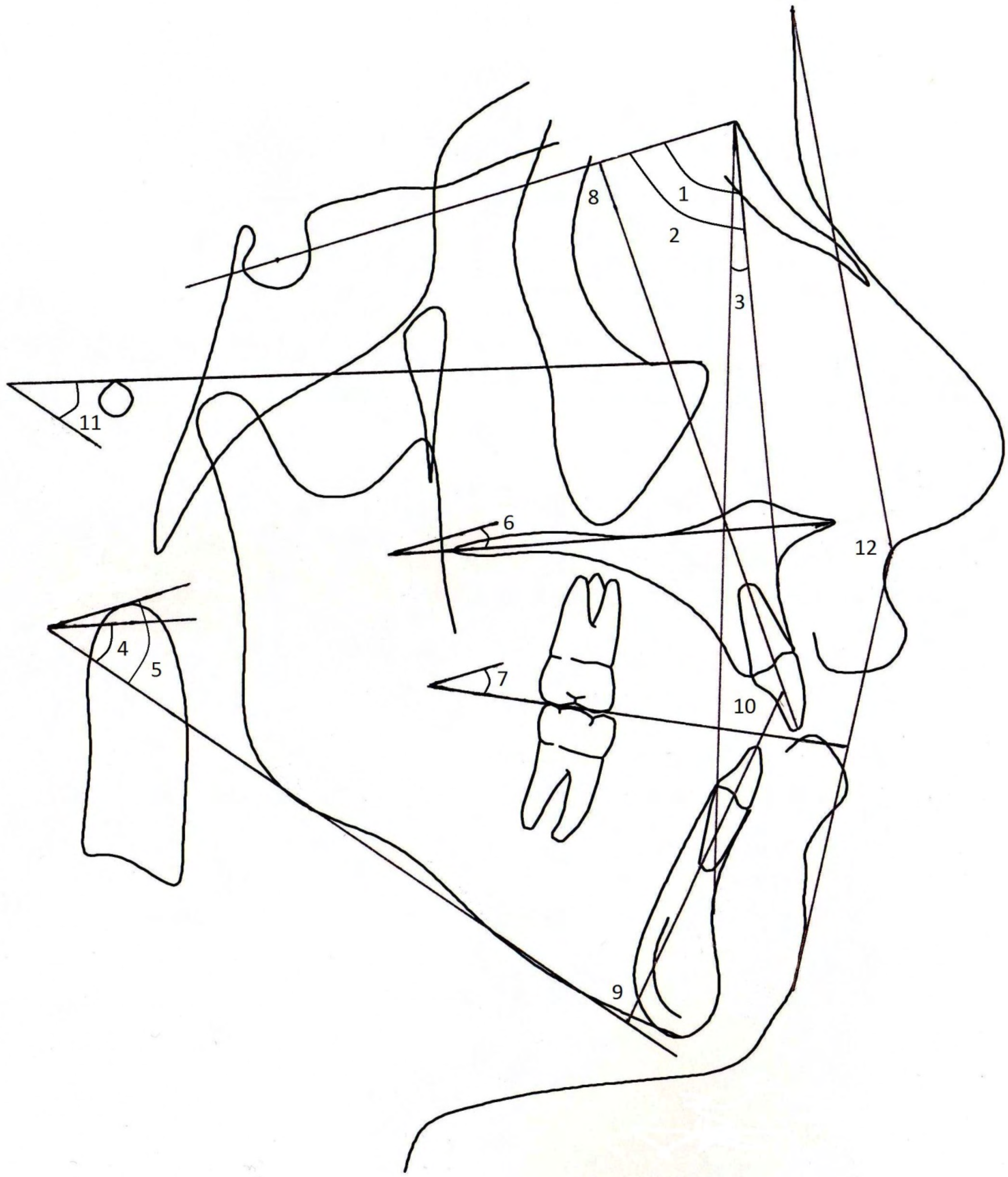


Occlusal View

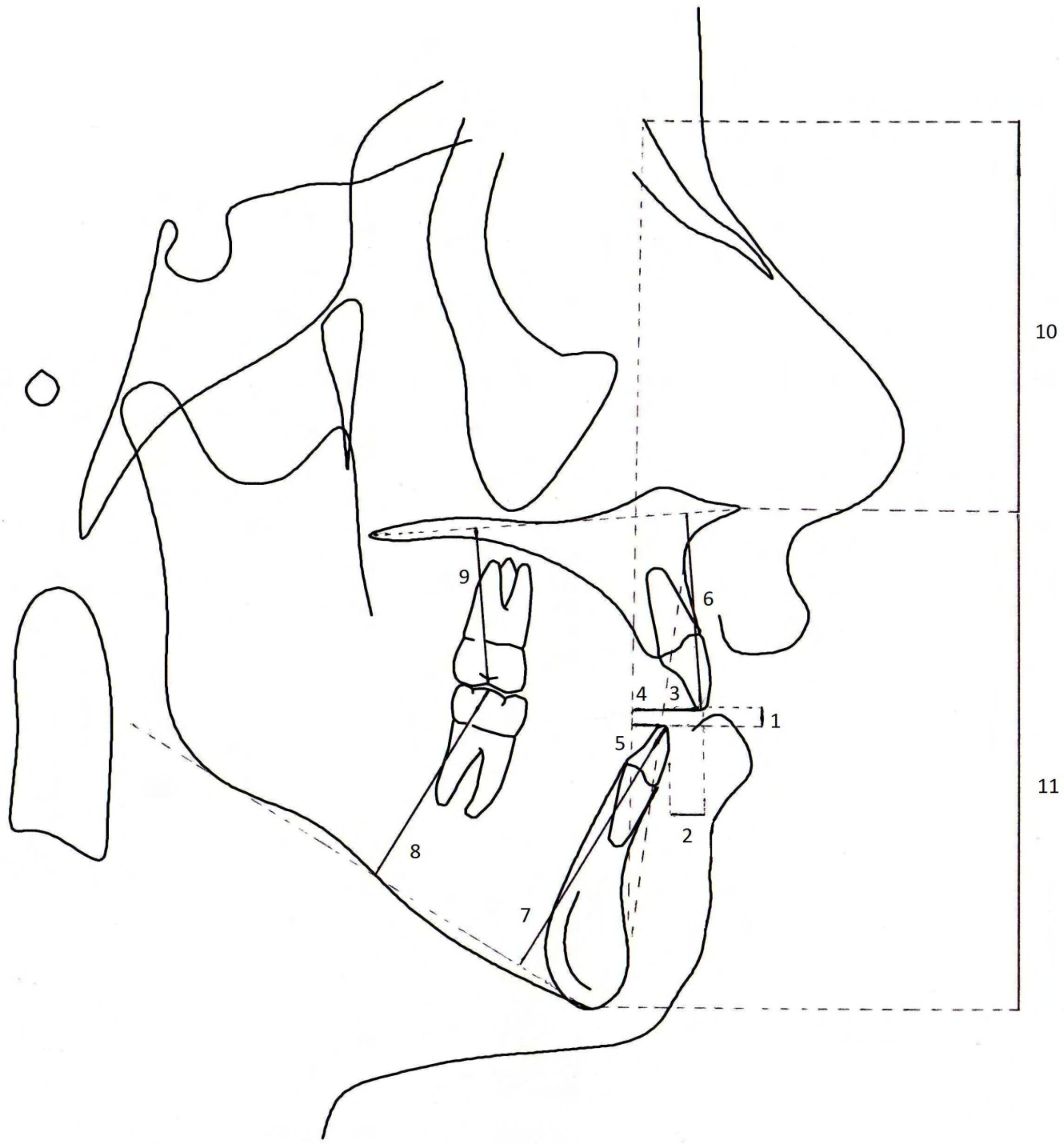
Intra oral Right

Intra oral Left

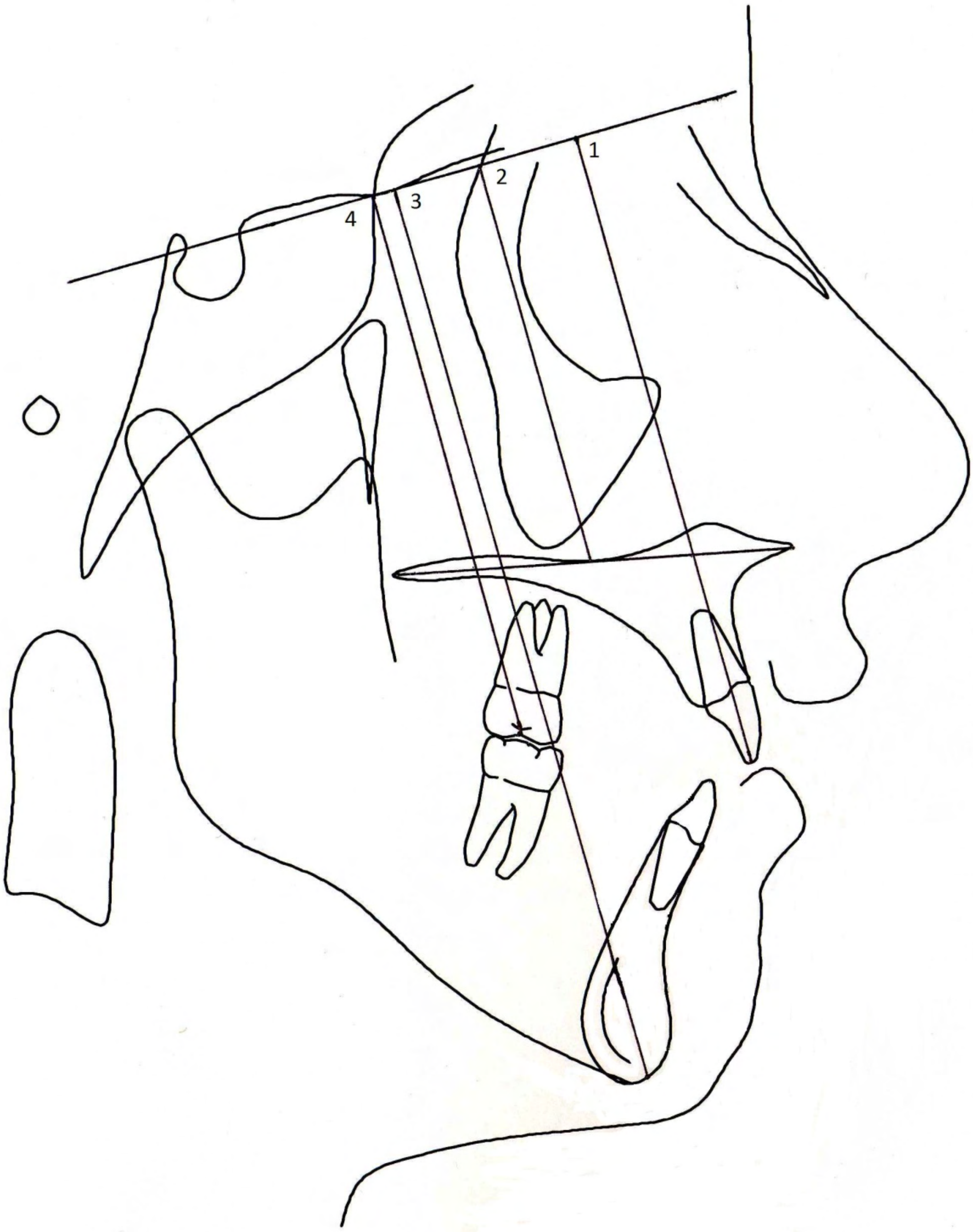
Figure 5- Cephalometric landmark identification and legend



a) **Angular measurements:** 1. SNA angle; 2. SNB angle; 3. ANB angle; 4. Mandibular plane to Palatal plane angle (PP/MP); 5. SellaNasion line to Mandibular plane angle (SN/MP); 6. SellaNasion line to Palatal plane angle (SN/PP); 7. Occlusal plane to SellaNasion line angle (Occ/SN); 8. Maxillary central incisor to SellaNasion line angle (U1/SN); 9. Mandibular central incisor GonionGnathion line angle (L1/GoGn); 10. Interincisal angle (U1/L1); 11. Mandibular plane to Frankfurt horizontal (MP/FH); 12. Facial convexity (G'Sn'Po')



b) **Linear measurements:** 1. Over bite; 2. Overjet; 3. Maxillary central incisor protrusion (U1-Apo); 4. Maxillary incisor to NasionPognion line (U1-NPo); 5. Mandibular central incisor to Mandibular plane (L1-MP); 8. Mandibular fist molar to Mandibular plane (L6-MP); 9. Maxillary first molar to Palatal plane (U6-PP); 10. Upper anterior facial height (UAFH); 11. Lower anterior facial height (LAFH)



c) **Stable Basicranial Line measurements:** 1. Measurement to Maxillary central incisor tip (SBL-U1); 2. Measurement to Palatal plane (SBL-PP); 3. Measurement to Maxillary first molar occlusal surface (SBL-U6); 4. Measurement to Gnathion (SBL-Gn)

Figure 6- Sydney Intrusion Spring (SIS) force delivery graph

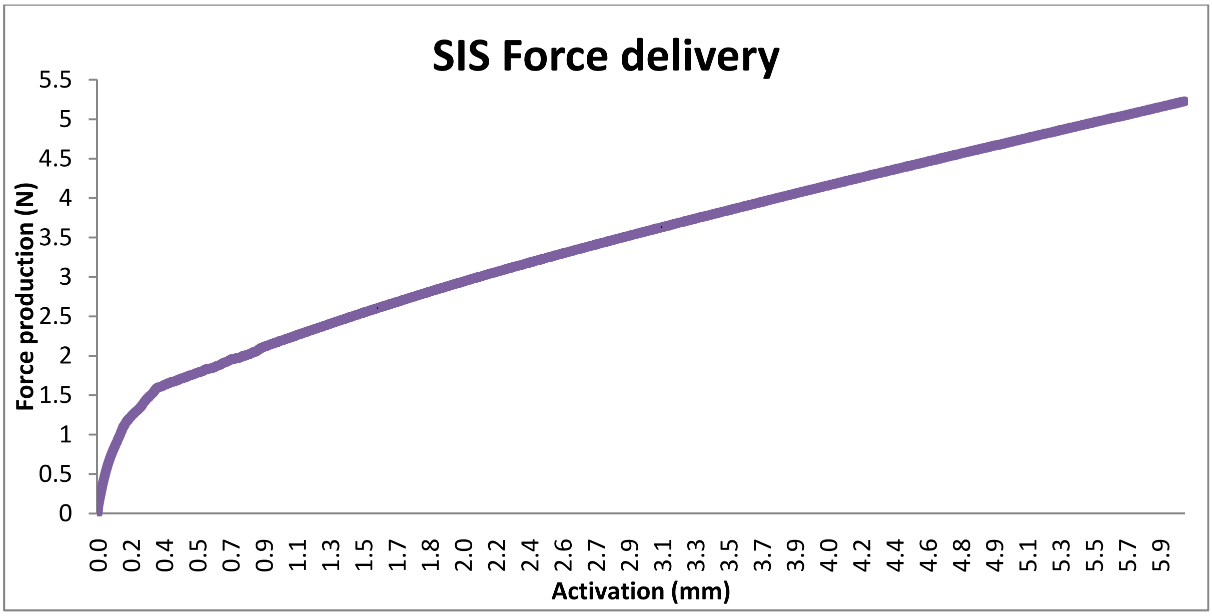


Figure 7- Posterior open bite, post intrusion, due to anterior occlusal interferences

Frontal View

Intra oral Right

Intra oral Left

Figure 8- Maxillary regional superimposition

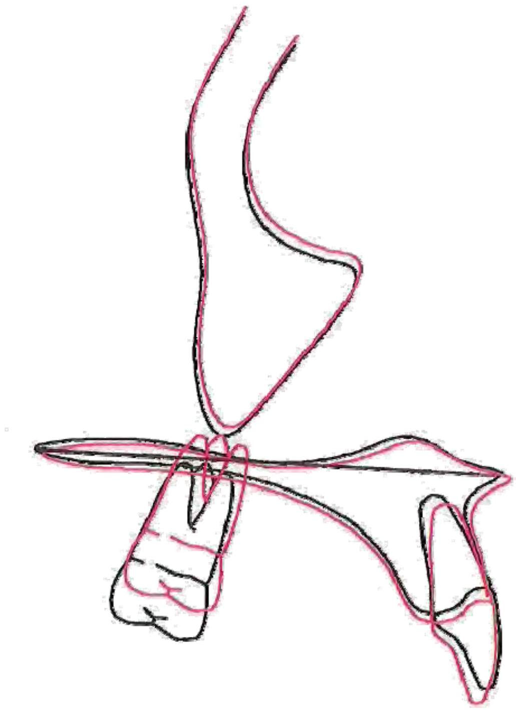
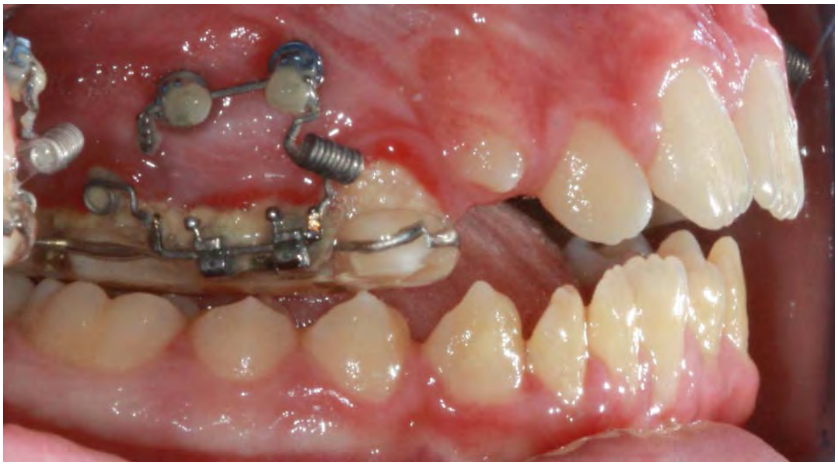


Figure 9- Sydney Intrusion Spring (SIS) in the presence of poor oral hygiene

Frontal View



Intra oral Right

Intra oral Left

10.10 List of Tables

Table I- Summarized cephalometric changes from T1 to T2

	T1		T2		Difference			
	Mean	SD	Mean	SD	Mean	SD	P	Significance
ANB (º)	4.8	2.9	4.5	2.8	-0.4	0.9	.139	NS
SNA (º)	81.6	5.7	81.8	5.8	0.2	0.5	.183	NS
SNB (º)	76.8	4.8	77.4	5.4	0.6	1.0	.054	NS
PP-MP (º)	31.8	3.8	30.7	4.3	-1.0	1.3	.009	**
U1 -SN (º)	107.3	8.5	102.8	8.3	-4.5	3.3	.000	***
Occ Plane to SN (º)	17.1	4.4	19.6	4.7	2.6	1.3	.000	***
SN -MP (º)	36.1	4.9	34.9	5.3	-1.2	1.3	.002	**
SN-PP (º)	7.1	2.7	7.0	2.6	-0.1	0.6	.647	NS
L1 -GoGn (º)	97.5	8.7	91.0	7.9	-6.6	3.8	.000	***
Interincisal Angle (º)	119.5	12.2	131.6	11.6	12.2	5.1	.000	***
(G'Sn'Po') (º)	160.5	5.5	160.1	5.8	-0.4	1.4	.256	NS
FMA (MP-FH) (º)	27.8	3.5	26.9	3.6	-0.9	1.2	.015	*
Over bite (mm)	-2.2	1.7	0.8	1.1	3.0	1.5	.000	***
Overjet (mm)	4.5	2.3	4.4	1.8	-0.1	1.2	.900	NS
U1-Apo (mm)	8.6	3.1	7.4	3.1	-1.2	0.9	.000	***
U1 -NPo (mm)	11.1	4.3	9.6	4.0	-1.5	1.2	.000	***
U1 -PP (mm)	25.6	2.3	26.5	2.4	0.9	0.6	.000	***
L1-APo (mm)	4.1	3.3	3.0	3.2	-1.2	0.9	.000	***
L1-MP (mm)	34.7	2.8	36.1	2.7	1.4	0.8	.000	***
L6 -MP (mm)	27.9	2.9	28.0	2.9	0.1	0.4	.201	NS
U6 -PP (mm)	20.6	2.3	17.7	2.4	-2.9	0.8	.000	***
LAFH (mm)	61.8	4.3	60.9	4.6	-0.9	1.1	.009	**
UAFH (mm)	48.6	3.4	48.6	3.3	0.0	0.7	.908	NS
U6-Mx ref plane (mm)	20.5	2.4	17.8	2.3	-2.7	0.7	.000	***
SBL-U6	69.9	4.6	66.7	4.8	-3.2	0.6	.000	***
SBL-U1	82.3	5.7	83.1	5.6	0.9	0.8	.000	***
SBL-PP	52.0	4.0	52.4	3.8	0.4	0.4	.000	***
SBL-Gn	110.6	7.5	109.6	7.5	-1.0	1.4	.016	*

11. Future directions

The Sydney Intrusion Spring (SIS), a purposely designed intrusion auxiliary, is an effective appliance for the intrusion of maxillary posterior teeth, used in conjunction with miniscrew TSAD's.

The appliance is able to achieve clinically significant intrusion over a large range of activation, with minimal maintenance and requirement for reactivation.

The presence of the appliance is well tolerated by patients and resulted in minimal tissue irritation and no gingival overgrowth.

The results of the present study indicate that the Sydney Intrusion Spring (SIS) is an effective appliance for the intrusion of maxillary posterior teeth, in conjunction with miniscrew TSAD's. The present results however only relate to the initial intrusion achieved through the use of this appliance and further study is currently ongoing to follow up these subjects through the fixed appliance phase of treatment. It will be interesting to witness the pending results of that study and it is hoped that most of the intrusion achieved, will be maintained.

Further studies are also suggested to explore the effectiveness of the SIS appliance in the correction of anterior open bite malocclusions in a non-growing subject group and on subjects with a larger initial anterior open bite than our current subject population. The study of non growing subjects will allow for direction comparison with the current literature on TSAD's based molar intrusion. Larger initial anterior open bite malocclusions will allow for greater increments of molar intrusion and test the limits to which the SIS is able to correct these malocclusions.

Following the present study, limited autorotation of the mandible and reduction in lower anterior face height were achieved and a posterior open bite was often observed, due to anterior occlusal interferences, after appliance removal. It would be possible to bond fixed appliances to the anterior teeth and attach these to the intrusion appliance through the auxiliary slot on the brackets in the bonded acrylic appliance. It is suggested that this arrangement might lead to the eradication of the observed anterior occlusal interferences following intrusion, which will allow for greater mandibular autorotation and reduction in the anterior facial height.

Some studies suggest that the presence of posterior bite blocks and/or an expansion screw in the appliance assists in the intrusion achieved of the maxillary posterior teeth. Posterior bite blocks are thought to achieve dento-alveolar intrusion through the forces of occlusion and the expansion screw through upward intrusive pressure from the tongue. It would therefore be prudent to investigate the effects of different appliance design on the amount of intrusion achieved. One might opt to use a banded type appliance and/or some form of arch stabilisation that does not interfere with the tongue position.

Skeletal anterior open bite individuals frequently present with a concurrent Class II, mandibular retrognatic malocclusion. A subsequent avenue of exploration for future generations of the SIS would be the incorporation of the SIS into a fixed functional appliance or vice versa. This would allow for simultaneous vertical, antero-posterior and even transverse correction of the malocclusion with virtually no patient compliance required.

The present study employed miniscrew TSAD's a source of stationary anchorage, but a prototype miniplate with a bracket like attachment on the gingival aspect has also been conceptualized. Further study is needed into the use of the SIS in conjunction with different types of temporary skeletal anchorage devices.

Currently the SIS attaches to the teeth via brackets on the bonded acrylic appliance and to the miniscrews via steel ligation. Ligation to miniscrews in the maxillary buccal sulcus in itself presents a technical challenge, not to mention the potential risk of soft tissue trauma due to dislodged wire ends. Alternative means of attachment to the miniscrews have therefore for been suggested and a prototype magnetic cap attachment is currently in development to improve the reliability and ease of attachment to the miniscrews.

Although the presence of the SIS was well tolerated by all patients, concerns have been raised regarding the bulk of the current design. This bulk stems from the length of wire required in the helices to achieve the desired force delivery characteristics from the appliance. The 0.016" β-titanium wire used for the construction of the helices is the smallest diameter β-titanium wire currently commercially available, to our knowledge. Strategies for reducing the appliance bulk, whilst maintaining the force delivery characteristics would centre on either reducing the diameter of wire used, or the changing the type of material used, in the construction of the helices. Reduction of the wire diameter, if it were available, would possibly raise questions as to appliance durability and possible breakages, especially at the helix/frame interface. Changing the material type, to NiTi for instance, would present its own challenges. A wire material with a lower force deflection rate, like NiTi, might not present enough rigidity to maintain deformation of the appliance. NiTi also has very poor joinability and using multiple wire sizes in the same appliance, might therefore not be viable.

It has been our clinical observation that the SIS produces less tissue irritation and gingival hyperplasia than conventional intrusion auxiliaries. It appears to be superior in regards to hygiene, even in the presence of poor oral hygiene. This however needs to be confirmed in the future using scientific, quantifiable methods. Intra patient comparison of different intrusion auxiliaries, although challenging, would be ideal.

Currently no ideal force level for maxillary posterior teeth intrusion has been described in the literature. The SIS produces what can be considered a moderately high, initial intrusive force. High magnitude intrusive forces have frequently been associated with an increase in the risk and incidence of OIIRR, in the literature. Cursory evaluation of the CBCT data from the current study does not suggest the occurrence of any gross OIIRR, but this data should be more closely evaluated in a future study. The limited interradicular space present in some subjects would also warrant the investigation into the occurrence if any of the iatrogenic root damage that might have arisen during the study.

The current investigation utilised measurements taken from rendered cephalograms and reconstructed from CBCT scans. Ideally one would like to assess the effects of treatment of all three dimensions, but currently the technology for this is still in its infancy and the landmarks that may be used are not well defined. Once this technology becomes more evolved and 3D landmarks are more clearly defined it would be possible to reassess the current data and describe the effect of the this intervention on the facial skeleton and teeth more completely in all three dimensions.

12. Appendix

Appendix 1- Three dimensional superimposition, Subject KB

Appendix 2- Subject ME, prior to appliance placement

Appendix 3- Subject ME, at start of active intrusion

Appendix 4- Subject ME, at end of active intrusion

Appendix 5- Subject ME, after appliance removal

Appendix 6- The Sydney Intrusion Spring

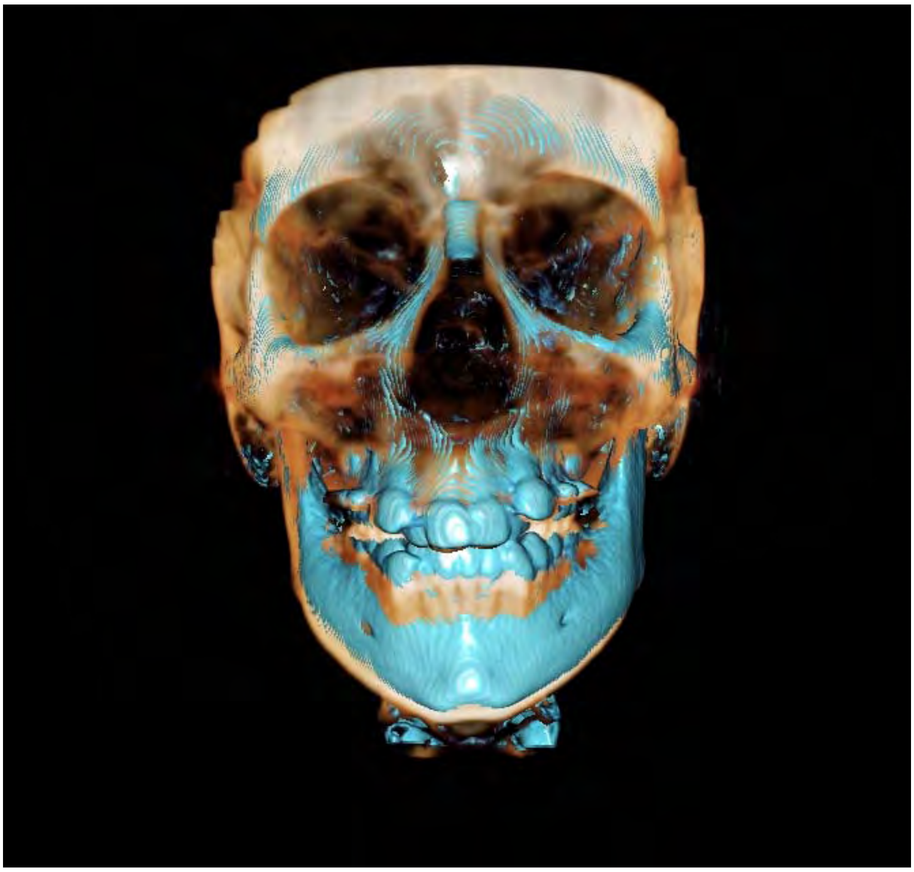
Appendix 7- Sydney Intrusion Spring laboratory testing

Appendix 8- Baasel Lasertec, Dentaurum desktop laser welder

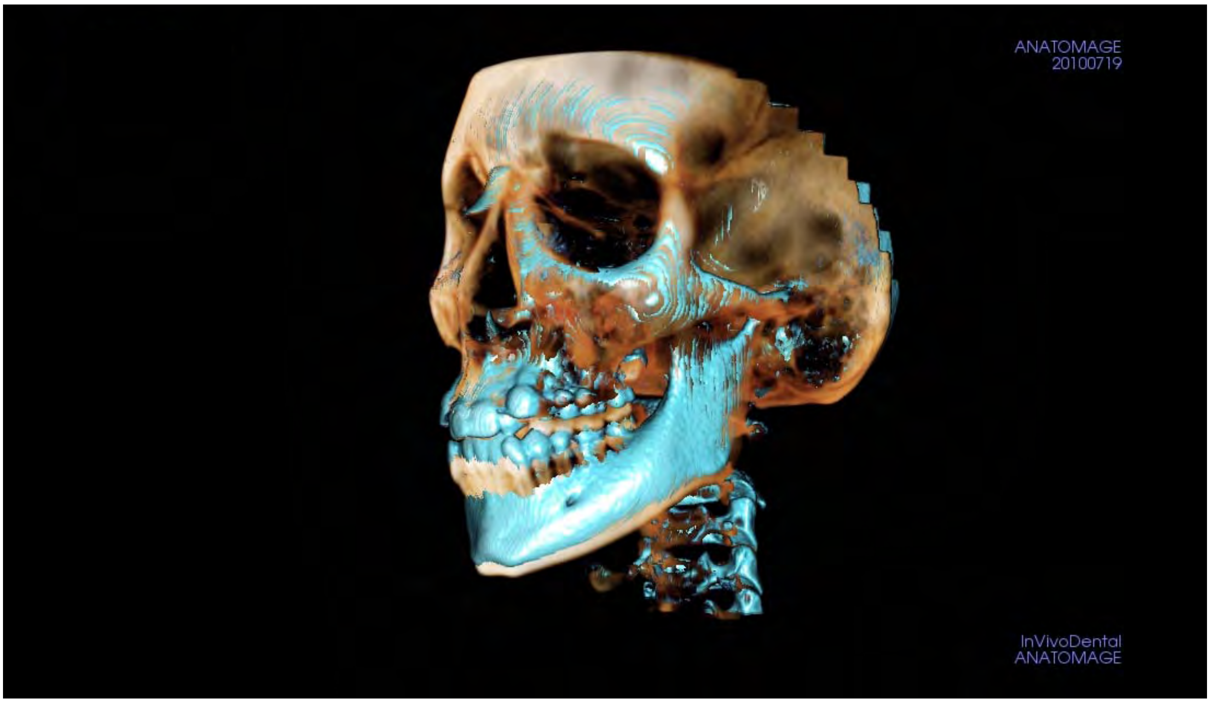
Appendix 9- Cephalometric measurements of subjects at T1

Appendix 10- Cephalometric measurements of subjects at T2

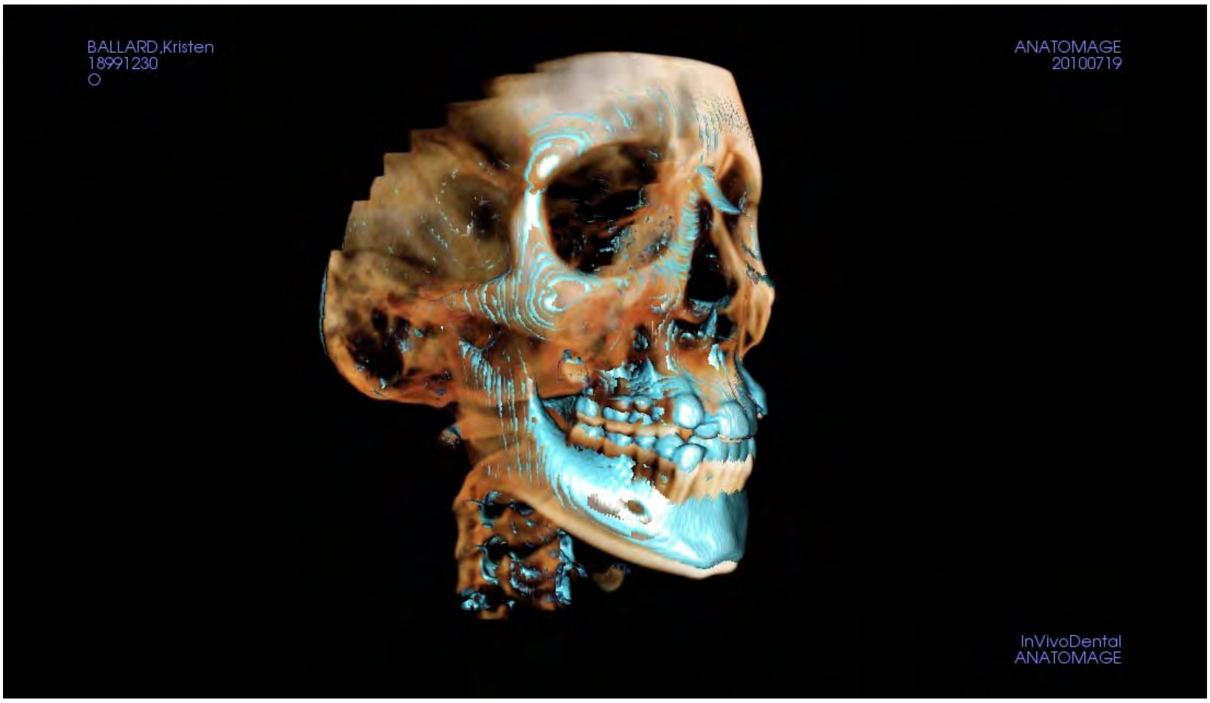
Appendix 1- Three dimensional superimposition, Subject KB



a) Frontal View



b) Left three-quarter View



c) Right three-quarter View

Appendix 2- Subject ME, prior to appliance placement

A) Extra oral photographs

B) Intra oral photographs

Appendix 3- Subject ME, at start of active intrusion





Appendix 4- Subject ME, at end of active intrusion



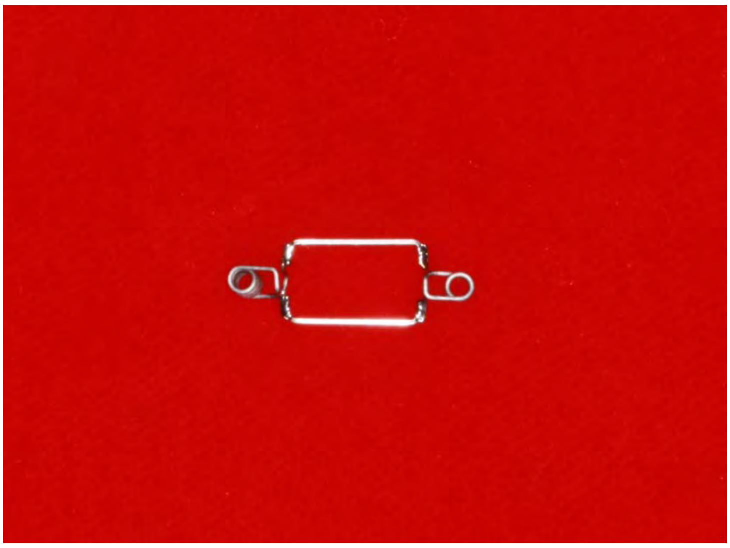


Appendix 5- Subject ME, after appliance removal

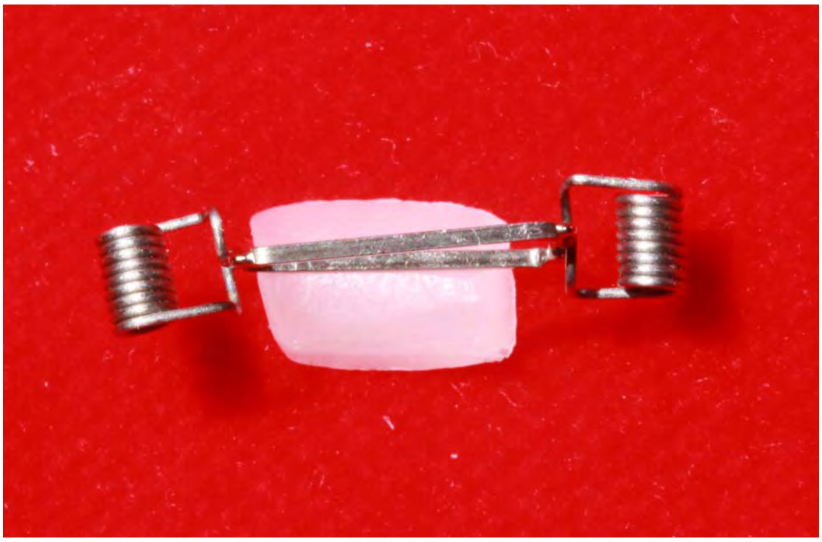
A) Extra oral photographs

B) Intra oral photographs

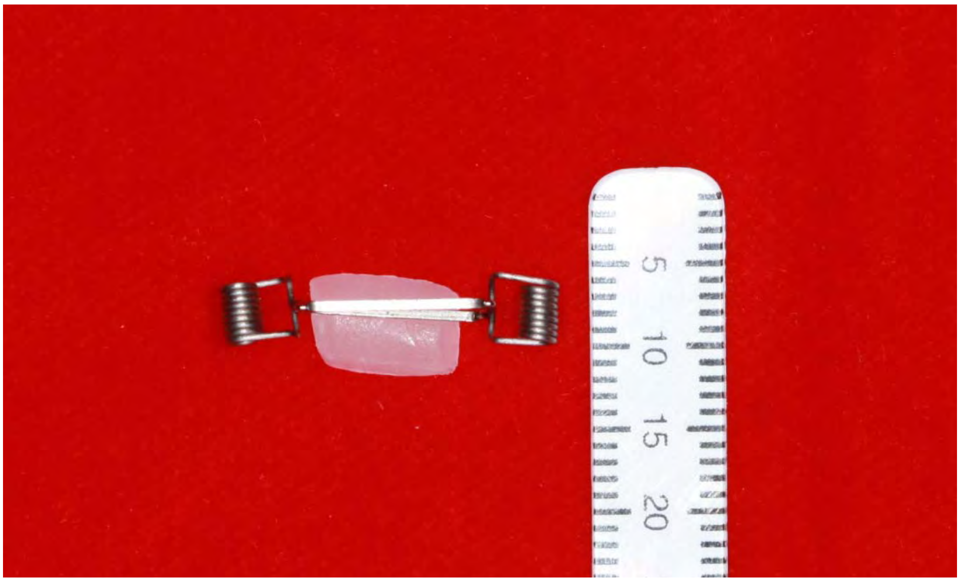
Appendix 6- The Sydney Intrusion Spring



a) Side view



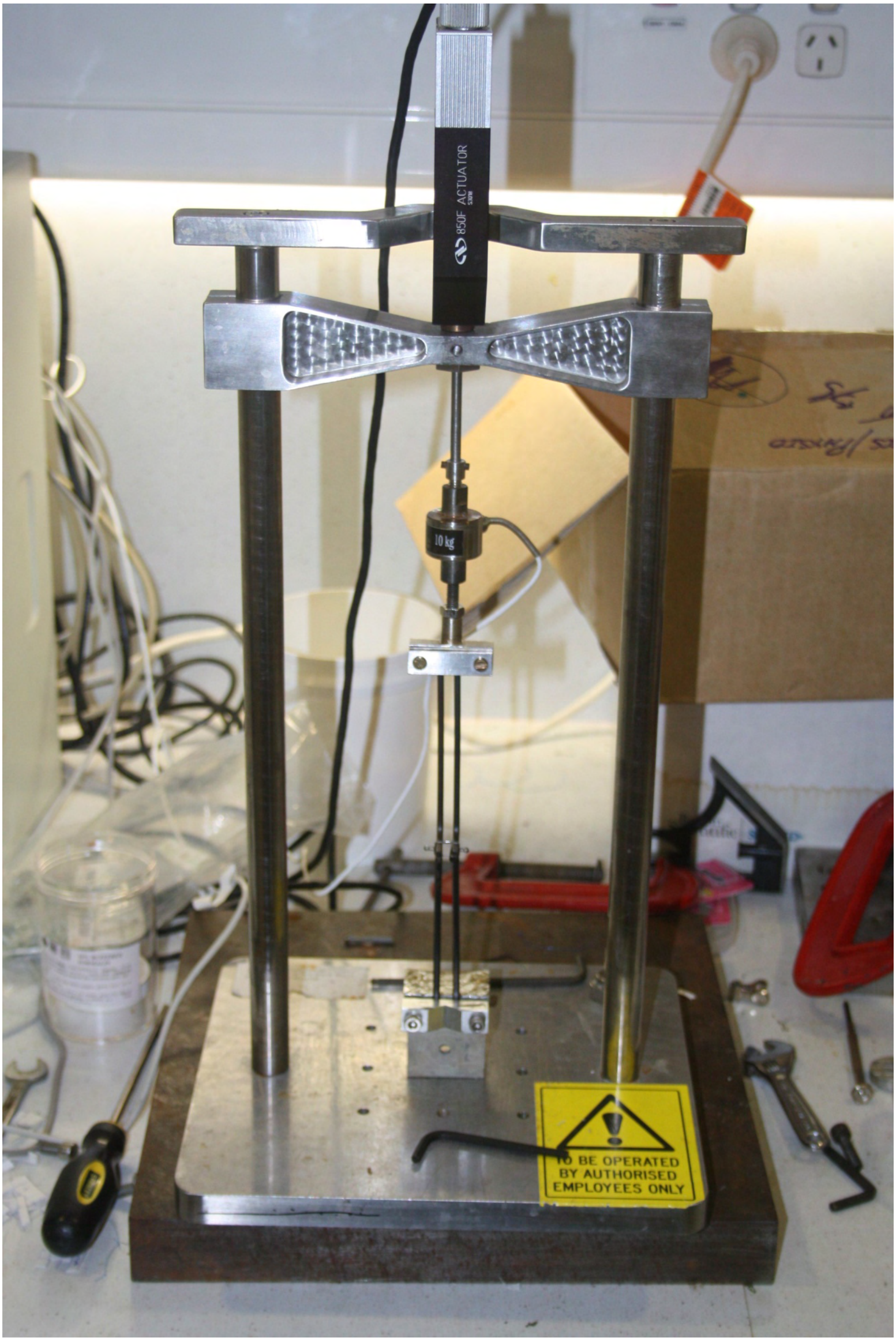
b) Top view



c) Dimensions: Width

d) Dimensions: Length

Appendix 7- Sydney Intrusion Spring laboratory testing



Appendix 8- Baasel Lasertec, Dentaurum desktop laser welder

Appendix 9- Cephalometric measurements of Subjects at T1

Measurements T1:	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8	Subject 9	Subject 10	Subject 11	Subject 12	Subject 13	Subject 14	Subject 15	Subject 16
ANB (º)	2.2	8.7	2.6	7.2	1.6	4.9	4.6	1.2	6	4.3	6.6	10.6	5.8	6.5	-0.2
SNA (º)	82.5	86.6	81.8	78.9	72.4	73.1	82	79.4	81.1	90.7	81.4	93.2	78.4	86.4	76.8
SNB (º)	80.4	77.9	79.1	71.7	70.8	68.2	77.4	78.2	75.1	86.4	74.9	82.7	72.6	79.8	77
PP-MP (º)	34.1	25.9	31.2	36.1	35	31.4	34.9	37	31.6	29.2	28.5	25.3	35.9	27.9	32.5
U1 -SN (º)	103.6	101.2	101.9	92.3	108.8	104.2	107.4	104.5	106.5	129.9	106.3	117.1	104.3	105.3	115.7
Occ Plane to SN (º)	17.2	15.9	20.3	24.9	21.7	21.9	13.7	19.6	14.5	9.3	11.9	16.4	19.8	17.4	11.6
SN - MP (º)	36.6	28.7	36.2	45.7	42.3	40.7	34.7	38.8	37.6	30	32.1	30	41.4	32.9	34.5
SN-PP(º)	5.7	7.8	7.4	12	10.2	11.1	2	4.6	7.8	4.6	5.8	7.2	7.5	7.8	4.8
L1 -GoGn (º)	93.9	103.1	100.8	84.5	95.8	103.6	92.9	88.6	96.1	102.6	101.9	120.7	98	89.8	90.8
Interincisal Angle (º)	126.5	127.5	121.6	137.9	113.4	112	125.4	128.7	120.1	97.6	120.1	92.3	116.8	132.6	119.4
Over bite (mm)	-1.3	-1.1	-3.2	-2.9	-1.9	1.2	-1.8	-2.4	-1.2	-5.4	-1.4	-5.8	-1.4	-2	-2.1
Overjet (mm)	0.4	7.6	2.7	4.7	1.8	6	6.4	-0.3	4.9	3.9	5.9	5.4	5.4	5.9	5.6
U1-APo (mm)	5.2	8.2	7.7	5.3	9.3	9.4	8.8	5.4	7.4	12.1	10.1	17	9.8	5.7	6.9
U1 -NPo (mm)	6.4	12.2	9.2	9.6	10.4	11.7	10.4	6.4	10.4	14.9	13.5	23.3	12.8	8.6	6.1
U1 -PP (mm)	28.3	23.8	23.7	26.9	24.6	25.2	26.8	28.5	24.1	21.2	27.6	25.7	28.5	21.9	27
L1-APo (mm)	4.7	0.7	4.7	0.6	7.5	3.3	2.3	5.4	2.6	8.3	4.5	11.9	4.4	-0.2	1.2
L1-MP (mm)	38.6	32.1	29.9	36.1	32.7	34.1	35.2	37.6	35	35.3	37.4	30.3	34.2	32.5	39.3
L6 -MP (mm)	30.8	25	25	29.3	27.4	28.1	26.8	29.6	26.3	27.4	30.5	31.2	26.5	25.5	29
U6 -PP (mm)	22.5	19.1	17	21.4	18.5	18.5	20.9	21.6	21.1	20.1	24.5	21.7	21.2	17.2	24.3
LAFH (mm)	67.7	56.2	56.2	66	59.8	58.4	61.4	67.8	60	60.8	65.4	61	63.1	55.5	67.4
UAFH (mm)	52.4	46.9	48.3	53.3	50.9	51.9	49.9	53.3	45.8	42.1	45.9	48.2	50.2	45.2	44.8
Facial Convexity (º)	152.9	156.1	165.2	156	161.7	152	163.2	162.4	159.7	169	161.7	162.1	154.1	161.8	170.1
FMA (MP-FH) (º)	29.1	21.9	25.2	33.2	30.8	28.6	25.4	28.9	27.6	25.3	23.7	23.6	33.2	28.1	31.7
Mx ref line-U6	21.9	19.9	16.5	21.1	17.3	18.2	20.9	21.6	21.1	20.1	24.5	21.7	21.2	17.1	24.3
SBL-U6	77	66.2	66.2	70.5	66.4	64.8	73.1	76.8	75.2	65.1	72.3	71.9	69.5	62.5	71.5
SBL-U1	92	82.9	83.9	83	78.8	77.9	82.1	91.9	75.1	73.8	83.8	85.9	87	74.1	81.7
SBL- PP	59.1	53.1	53.9	52.1	51.1	47.4	54.1	59.5	46.5	47.3	50.3	54.1	53.1	47.8	50.4
SBL-Gn	124.1	102.8	113.5	115.7	104.9	106.1	113.6	124.4	101.6	103.5	111.2	110.8	111.7	100.5	114.6

Appendix 10- Cephalometric measurements of Subjects at T2

Measurements T2:	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8	Subject 9	Subject 10	Subject 11	Subject 12	Subject 13	Subject 14	Subject 15	Subject 16
ANB (º)	1.3	8.6	2.5	6.6	3.7	4.9	3.7	1.2	6.4	2.5	5.3	9.6	5.2	6.6	-1
SNA (º)	82.4	86.8	82.7	78.9	72.4	72.4	82	79.4	81	90.7	81.4	93.2	79.5	87.4	77.1
SNB (º)	81.2	78.3	80.2	72.3	68.7	67.5	78.2	78.2	74.7	88.2	76.1	83.6	74.3	80.8	78.1
PP-MP (º)	35	25.9	28.8	34.9	35	32.2	34.9	37	30.7	25.7	26.6	24.3	34.1	26.1	30
U1 -SN (º)	103.2	94.5	101.6	93.1	102.4	97.3	103.5	96	103.7	122.6	103	114.1	97.5	95.3	113.8
Occ Plane to SN (º)	18.3	19.7	21.3	29.6	25.3	24.1	17.3	21.9	16.8	11.4	13.8	16.8	21.1	21.5	15.4
SN - MP (º)	36.9	28.4	35.1	43.6	42.4	40.9	34.5	38.5	36.7	26.6	30	29.3	38.2	31.3	31.6
SN-PP(º)	5.3	7.7	8.9	11.1	10.2	10.9	2	4.6	7.8	4.6	5.8	7.2	6.3	8.4	4.4
L1 - GoGn (º)	86.6	97.8	87.4	85	94.1	93	87	75.7	91.3	96.5	94.4	111.7	91.3	86.1	86.9
Interincisal Angle (º)	133.7	139.7	136.4	138.7	121.5	128.9	135.2	150.1	128.7	114.5	132.8	105.2	133.2	147.3	127.9
Over bite (mm)	0.4	1.1	-1.3	0.4	1.9	2.6	-0.6	-0.2	1	0.4	2.2	0	1	2.5	0.3
Overjet (mm)	0.6	6.6	3.8	5.1	5	6.5	6.5	0.8	5.1	2.8	5	5	5.1	4	5
U1-APo (mm)	5.9	6.5	7.1	5.5	9.4	7.8	8	4	6.1	10.2	8.2	16.1	7.9	2.9	5.2
U1 -NPo (mm)	6.6	10.4	8.5	9	11.5	10.1	9.6	5	9.2	11.8	10.7	21.6	10.3	5.7	3.9
U1 -PP (mm)	29.4	24.9	24.1	28.8	25.7	25.4	28	28.9	23.8	23.1	28.8	26.6	29.7	23	27.6
L1-APo (mm)	5.4	-0.1	3.2	0.5	4.4	1.3	1.4	3.1	1	7.5	3.1	11.1	2.8	-0.7	0.3
L1-MP (mm)	40.4	33.8	31.6	36.7	33.5	35.1	35.6	39.5	35.7	37.3	38.8	33.8	36.1	33.8	40
L6 -MP (mm)	30.7	26	24.7	30.1	27.6	27.7	26.8	29.8	26.3	27.7	30.5	31.2	26.5	25.5	29.2
U6 -PP (mm)	20.7	15.4	15.3	18.1	15.7	15.7	18.6	19.1	17.9	16.3	22.5	18.6	18.6	13.3	20.3
LAFH (mm)	68.7	56.3	56.6	64.5	57.1	57.7	61.4	67.8	57.8	58.9	64.3	59.7	63.4	53.6	66
UAFH (mm)	52.8	47.4	48.3	52.2	50.9	51.9	49.9	53.3	46.6	42.1	45.9	48.2	48.9	46.6	44.4
Facial Convexity (º)	152	155.4	163.8	153.7	157.9	152.2	163	162.4	158.4	169.2	163.2	163.2	155	161.3	170.9
FMA (MP-FH) (º)	29.2	22.4	24.8	32	30.8	29.4	25.4	28.9	26.7	21.8	21.8	22.6	31.4	27.2	29.2
Mx ref line-U6	20	16.3	14.9	17.9	15.2	15.5	18.6	19.1	18.3	16.3	22.5	18.6	18.5	14.3	20.3
SBL-U6	76.1	63.5	64.4	66.8	63.7	62.1	70.8	74.1	63.1	61.3	70.8	69	66.9	59.7	67.9
SBL-U1	93.8	84.1	84.8	84.1	79.8	77.5	83.2	92.1	75.6	75.4	84.7	86.7	87.1	76.7	81.9
SBL- PP	59.5	53.9	54.1	52.9	51.2	47.6	54.3	59.6	47.6	47.6	50.4	54.3	53.5	49.1	50.9
SBL-Gn	123.7	103.1	113.2	111.4	104.3	106.5	113	124.1	101.1	101.3	110.4	107.4	112.7	99.1	112.5