

T.C.

MARMARA ÜNİVERSİTESİ
SAĞLIK BİLİMLERİ ENSTİTÜSÜ
ORTODONTİ ANABİLİM DALI

***İKİ HIZLI KANİN RETRAKSİYONU YÖNTEMİNİN
KARŞILAŞTIRILMASI VE DEĞERLENDİRİLMESİ:***

ALVEOLAR KEMİK DİSTRAKSİYON OSTEONEZ YÖNTEMİ

VE

***PERİODONTAL MEMBRAN DİSTRAKSİYON OSTEONEZ
YÖNTEMİ***

YÜKSEK LİSANS TEZİ

T 91404

**DİŞ HEKİMİ
MOHANNAD Z. Y. AL-HAJJI**

DANIŞMAN: YRD. DOÇ. SİBEL BİREN

**T.C. YÜKSEKÖĞRETİM KURULU
DOKÜMANTASYON MERKEZİ**

İSTANBUL - 1999

CONTENTS

	Page No.
DEDICATION.	i
ACKNOWLEDGMENTS.	ii
ABSTRACT.	iii
ÖZET.	v
ABBREVIATIONS.	vii
1. INTRODUCTION:	1
1.1. Rationale.	1
1.2. Hypothesis.	1
1.3.1. General objectives.	2
1.3.2. Specific objectives:	2
1. Assessment of and comparison between the characteristics of two rapid canine retraction techniques: regarding the rate of retraction, the nature of tooth movement (tipping versus translation) and anchorage loss.	2
2. Assessment of alveolar bone formation and remodeling after rapid canine retraction.	3
3. Assessment of root resorption during and after rapid canine retraction.	5
4. Assessment dental pulp vitality after rapid canine retraction.	6
5. Assessment of periodontal health after rapid canine retraction.	7
6. Assessment of prevalence, intensity, and duration of pain or discomfort perception associated with rapid canine retraction.	8
2. RAPID TOOTH MOVEMENT:	9
2.1. Introduction.	9
2.2. Historical review.	9
2.3. Surgical considerations: complete subapical osteotomy <i>versus</i> subtotal subapical osteotomy:	14
2.3.1. Complete subapical osteotomy.	14
2.3.2. Subtotal subapical osteotomy.	15
2.4. Results of animal experiments analyzing possible injuries due to osteotomy in	

the alveolar bone:	16
2.4.1. Injuries to the periodontal membrane.	17
2.4.2. Injuries to the cementum and dentin.	17
2.4.3. Injuries to the pulp.	18
2.5. Discussion of rapid tooth movement with subtotal osteotomy.	19
• Figures.	23
3. DISTRACTION OSTEOGENESIS:	26
3.1. Introduction.	26
3.2. Historical review:	26
3.2.1. Origins.	26
3.2.2. In the field of plastic surgery.	27
3.2.3. Mandibular reconstruction.	28
3.2.4. Maxillary and midfacial reconstruction.	29
3.2.5. Other applications.	29
3.3. Bone healing during and after distraction osteogenesis.	30
3.4. Factors influencing osteogenesis during distraction:	32
3.4.1. Surgical factors.	32
3.4.2. Postoperative factors.	33
3.4.3. Mechanical factors.	34
3.4.4. Patient-related factors.	34
3.5. Soft tissue healing during and after distraction osteogenesis:	35
3.4.1. Connective tissues.	35
3.4.2. Muscular tissues.	36
3.4.3. Vascular tissues	37
3.4.4. Nervous tissues.	37
3.4.5. Skin reactions.	38
3.6. Distraction appliances.	38
• Figures.	40
4. STUDY DESIGN:	46
4.1. Study subjects: <i>sample size and inclusion criteria.</i>	46

4.2. Clinical protocol.	46
4.3. Events schedule.	47
4.4. Methods:	48
4.4.1. Assessment of and comparison between two rapid canine retraction techniques: regarding the rate of retraction, the nature of tooth movement (tipping versus translation) and anchorage loss.	48
4.4.2. Assessment of new alveolar bone formation and remodeling after rapid canine retraction.	51
4.4.3. Assessment of root resorption during and after rapid canine retraction.	52
4.4.4. Assessment of dental pulp vitality after rapid canine retraction.	54
4.4.5. Assessment of periodontal health after rapid canine retraction.	54
4.4.6. Assessment of prevalence, intensity, and duration of pain or discomfort perception associated with rapid canine retraction.	55
• Figures.	58
5. APPLIANCE DESIGN:	68
5.1. Appliance components:	68
5.1.1. Retentive components.	68
5.1.2. Active components.	68
5.1.3. Passive components.	68
5.2. mechanical considerations:	68
5.2.1. Treatment objective.	69
5.2.2. Required center of rotation.	69
5.2.3. Required force system:	69
(1) Force magnitude.	69
(2) Force direction.	70
(3) Force sense.	70
(4) Point of force application.	70
5.2.4. Equilibrium state of the force system in the three planes of space.	71

5.2.5. Appliance activation.	72
5.3. Appliance fabrication:	72
5.3.1. Clinical procedures.	72
5.3.2. Laboratory procedures.	73
• Figures.	74
6. SURGERY DESIGN:	81
6.1. Anesthesia.	81
6.2. Flap design:	81
6.2.1. Facial flap.	81
6.2.2. Palatal flap.	81
6.3. Osteotomy and corticotomy designs:	81
6.3.1. Alveolar bone distraction side.	81
6.3.2. Periodontal membrane distraction side.	82
6.4. Medicaments.	83
• Figures.	84
7. RESULTS:	89
7.1. Assessment of and comparison between the characteristics of two rapid canine retraction techniques: regarding the rate of retraction, the nature of tooth movement (tipping versus translation) and anchorage loss.	89
7.2. Assessment of alveolar bone formation and remodeling after rapid canine retraction.	92
7.3. Assessment of root resorption during and after rapid canine retraction.	93
7.4. Assessment dental pulp vitality after rapid canine retraction.	93
7.5. Assessment of periodontal health after rapid canine retraction.	94
7.6. Assessment of prevalence, intensity, and duration of pain or discomfort perception associated with rapid canine retraction.	94
• Figures & Tables.	96
8. DISCUSSION.	117
9. REFERENCES.	124
AUTOBIOGRAPHY.	135

TO MY BEST FRIEND WHO NEVER FAILED TO BE
INTELLECTUAL ENOUGH TO UNDERSTAND ME,
DELICATE ENOUGH TO CARE FOR ME,
KIND ENOUGH TO FORGIVE ME WHEN I MAKE MISTAKES,
STRONG ENOUGH TO GIVE ME POWER,
FAIR ENOUGH TO MAKE ME FEEL CONFIDENT,
WISE ENOUGH TO TRUST,
AND GENEROUS ENOUGH TO FIND TIME FOR ME WHENEVER I NEED TO TALK TO,
TO MY GOD.

ACKNOWLEDGMENTS

It is with great deal of pleasure that I like to thank those who contributed in so many ways to the completion of this project. I am indebted to my teachers and to my colleagues for keeping me challenged.

My gratitude is expressed to Dr. Imad Salih and Dr. Bahar Gürsoy, from Surgery department, Dr. Ender Kazazoğlu, from Prosthodontics department, Dr. Nevin Kartal, from Conservative Dentistry department, and Dr. Ulku Noyan, from Periodontology department in the Dental school of Marmara University for their ever helping efforts whenever needed.

And with affectionate appreciation, I like to thank my family for their continuous encouragement and for their unremitting support.



ABSTRACT

ASSESSMENT OF AND COMPARISON BETWEEN TWO RAPID CANINE RETRACTION TECHNIQUES : ALVEOLAR BONE DISTRACTION OSTEOGENESIS VERSUS PERIODONTAL MEMBRANE DISTRACTION OSTEOGENESIS

Two modalities of distraction osteogenesis were tangled in one clinical setting to assess and compare their efficiency in providing rapid canine retraction. In 2 adolescent patients with an initial mean age of 15 years, rapid retraction of 4 maxillary canines (including 2 right and 2 left) was carried out with custom-made, tooth-borne, intra-oral, unidirectional distraction devices utilizing modified jackscrews, which were inserted immediately after a minor surgical intervention and activated 0.8 mm a day after a three-day latency period. In each patient, the right maxillary canine was retracted by alveolar bone distraction (ABD) and the left one was retracted by periodontal membrane distraction (PMD). Retraction rate was faster at the ABD side (1.0mm/day) than at the PMD side (0.6mm/day). The nature of tooth movement was translation with minimal distal crown tipping (1.5°) at the ABD side, while it was a combination of translation and distal crown tipping (5.25°) at the PMD side. Anchorage loss in the posterior segment was minimal (0.25mm) with both techniques. Bone formation and remodeling was optimal in both modalities as was shown by densitometry. Root resorption was absent in both modalities as was shown by standard periapical radiography utilizing long cone paralleling technique in conjunction with custom-made radiographic splints. Pulp vitality was maintained with both techniques. Periodontal health was monitored pre-treatment and minimal changes were noticed post-treatment for both techniques. In addition, patients experienced only minimal to moderate discomfort during the retraction by ABD, while severe discomfort levels were noticed occasionally after appliance

activation in the PMD side, as was shown by the discomfort visual analogue scales.

In conclusion, rapid canine retraction was achieved more efficiently by alveolar bone distraction than with periodontal membrane distraction procedures, nevertheless, they both were effective and caused no detrimental effects to the surrounding physiologic environment.



ÖZET

İKİ HIZLI KANIN RETRAKSİYONU YÖNTEMİNİN KARŞILAŞTIRILMASI VE DEĞERLENDİRİLMESİ:

ALVEOLAR KEMİK DISTRAKSİYON OSTEONEZ YONTEMİ VE PERİODONTAL MEMBRAN DISTRAKSİYON OSTEONEZ YONTEMİ

Hızlı kanin retraksiyonu sağlamak amacıyla iki farklı distraksiyon osteonez yöntemi uygulanmıştır. Bir tarafta, alveoler kemik distraksiyonu [alveolar bone distraction (ABD)] diğer tarafa periodontal membran distraksiyonu (PMD) uygulanmıştır. Bu amaçla yaş ortalamaları 15 olan 2 yetişkin hastada 4 maksiller kaninin hızlı retraksiyonu yapılmıştır (2 sağ & 2 sol). Distraksiyon amacıyla prefabrike, dişe yapışan, intraoral, modifiye vidalar kullanılmıştır. Apareyler minor cerrahi operasyonundan hemen sonra yerleştirilmiş, 3 günlük bekleme periodundan sonra günde 0.8mm aktive edilmiştir. Her hastada sağ maksiler kanin ABD ile ve soldaki maksiller kanin PMD ile retrakte edilmiştir. Retraksiyon hızı ABD tarafında (1.0mm/gün), PMD tarafından (0.6mm/gün) daha hızlı gerçekleşmiştir. ABD tarafında diş hareketi translasyola birlikte minimal distal kron tippingi (1.5°) şeklindedir; PMD tarafında ise translasyon ve distal kron tippingi (5.25°) birlikte gerçekleşmiştir. Posterior bölgedeki ankraj kaybı her iki teknikte de minimaldir (0.25mm). Densitometrik olarak gösterildiği gibi kemik oluşumu ve yeniden şekillenmesi her iki teknikte de optimum seviyededir. Uzun kon paralel teknikle ve hazırlanan radyografik splintle elde edilen standart periapikal radyograflar üzerinde yapılan incelemede her iki tekniğin de kök rezorbsiyonuna yol açmadığı izlenmiştir. Pulpa canlılığı her iki teknikte de korunmuştur. Periodontal sağlık tedaviden önce tespit edilmiş ve tedavi sonrası her iki teknik için de minimum değişiklik göstermiştir. Hastalara verilen ağrı skalasına göre ABD ile retraksiyon süresince hastalar minimumla orta arası ağrı hissetmişler, PMD tarafında ise aktivasyon

ađrı hissetmiřlerdir.

Sonu olarak hızlı kanin retraksiyonunda ABD yntemi PMD ynteminden daha etkili olarak bulunmuřtur. Buna rađmen her iki yntem de etkili olup evre dokulara herhangi bir zararlı etkileri grlmemiřtir.



ABD: Alveolar Bone Distraction.

PMD: Periodontal Membrane Distraction.

RCR: Rapid Canine Retraction.

RME: Rapid Maxillary Expansion.

VAS: Visual Analogue Score.



1. Introduction:

1.1. Rationale:

The evolution of orthodontics since antiquity is characterized by innumerable efforts and remarkable inventiveness in developing new techniques for tooth movement.

John Tomes wrote in 1859 that light forces induced resorption of bony surfaces at the pressure side and bone formation on the tension side in the alveolus. Kingsly (1880) recognized the validity of Tomes' statement, but only when tooth movement was slow. With the application of a heavy force, bending of the alveolar bone occurred, whereby the tooth root and the alveolus were displaced together, yet maintaining their integrity[1]. Oppenheim[2] (since 1911), Schwartz[3] (since 1932), and others thereafter, reiterated that only light forces should be applied to teeth to avoid necrosis of periodontal tissues.

Rapid tooth movement without detrimental effect to the periodontal health is an overriding intent of a major sector of researchers in the field of orthodontics. This study is designed to embody pertinent knowledge to test the following hypothesis.

1.2. Hypothesis:

*We dance round in a ring and suppose
But the secret sits in the middle and knows.
Robert Frost¹, The secret sits*

Distracting the alveolar bone or the periodontal membrane can displace the alveolus and the tooth root together rapidly, yet without detrimental effect to the

¹ FROST, Robert (1874 - 1963), The works of the American poet Robert Frost tell simple things: swinging on a birch tree, stopping by woods on a snowy evening, the death of a hired man. Behind them is a deep feeling for life's fundamentals: respect, love, loyalty, awareness of nature and of God.

periodontal apparatus which used to result from heavy forces.

1.3. Objectives:

This clinical study is designed to investigate a potential technique that may help us move one tooth or a group of teeth rapidly, yet without detrimental effect to the surrounding physiologic environment.

1.3.1. General objectives:

Distraction osteogenesis can be induced by either **stretching a suture** or **stretching of a reparative bone tissue, that is called callus**, after an osteotomy or a corticotomy operation. In this study, we'll tangle the two modalities in one clinical setting to *assess* and *compare* their efficiencies in providing rapid canine retraction (RCR).

1.3.2. Specific objectives:

These involve the followings:

(1) **Assessment of and comparison between the characteristics of two RCR techniques:**

The concept of achieving rapid tooth movement by weakening the alveolar bone utilizing an osteotomy or a corticotomy is not new.¹ In 1896 Talbot[4] wrote of his many years' experience with a method of weakening the bone to facilitate orthodontic treatment. Bichlmayr[5] (1931) used that method in an Angle Class II malocclusion with dental protrusion and open bite. He carried out the movement of the teeth after extracting first premolars. A wedge-shaped bone resection on the alveolar process lingual to the anterior teeth was accomplished to facilitate retraction and alignment. However, the time required to accomplish the desired movement with orthodontic treatment was **several months**.

Gantes *et al.*[6] (1990) described a surgical technique with multiple corticotomies used in conjunction with orthodontic therapy to facilitate orthodontic tooth movement in five adult patients who exhibited different orthodontic problems. The mean treatment time was 14.8 months for the experimental group and 28.3 months for the control group. However, most of the orthodontic movement of the canines was accomplished in **seven months**.

Liou *et al.* [7] (1998) reported rapid retraction of twenty six canines, utilizing dental distraction of the periodontal ligament after minor surgical scoring of the interseptal bone at the time of the first premolar extraction.. They claimed that most of the canines were moved bodily 6.5 mm, in **three weeks**. In addition, their study results showed that 73% of the first molars did not move medially and 27% of them moved less than 0.5 mm medially within the retraction period.

We aim to assess and compare between two rapid canine retraction modalities, alveolar bone distraction *versus* periodontal membrane distraction, *regarding rate of retraction, nature of tooth movement (tipping versus translation), and anchorage loss in the posterior segment*.

(2) Assessment of new alveolar bone formation and remodeling after RCR:

Bone healing during and after distraction was investigated by many researchers[8,9,10]. It was studied using different experimental models like physeal distraction of long bones, distraction of long bones after osteotomy or corticotomy, and

¹ See section 2.2 for detailed historical review.

distraction of mandible after osteotomy or corticotomy. The mode of osteogenesis was essentially similar in all of these models[9].¹

Many authors described the osteogenesis process after experimental distraction procedures utilizing radiographic, histologic, and biochemical methods. Precise mineral content was inspected by measuring the amount of radiation absorption produced by an iodine-125 source in a clinical study, but it involves complex methodology that is only feasible in research[117]. In addition, dual energy photon x-rays (DEPX) technique was utilized in an experimental study, in animals, to measure the bone mineral content during distraction osteogenesis[118].

Bone densitometry is another technique that can be used to inspect bone mineral content. Although some authors reported poor correlation between radiographic density and the *biomechanical integrity* of newly formed bone[119,120], Cobo *et al.* [121] measured the course of bone formation in the midpalatal suture after rapid maxillary expansion by bone densitometry. Statistically significant changes in midpalatal suture density were evident throughout the period studied, since the beginning of expansion till five weeks later. Therefore, it was concluded that bone densitometry can be utilized to follow up the progression of bone formation.

Liou *et al.* [7] studied the alveolar bone healing on the medial side of a group of rapidly retracted canines utilizing periodontal ligament distraction. He described radiographic changes in five stages of bone formation and remodeling from the initiation of the retraction till the complete remodeling of the new alveolar bone.

¹ See section 3.3 for a detailed description of bone healing after distraction

We aim to assess and compare between two rapid canine retraction modalities, alveolar bone distraction *versus* periodontal membrane distraction, *regarding new bone formation and remodeling in the distracted zone.*

(3) Assessment of root resorption during and after RCR:

External root resorption is a serious iatrogenic problem associated with orthodontic treatment. It is believed to result from a complex combination of individual biology and the effects of mechanical forces. External root resorption is defined as either a physiologic or pathologic process resulting in the loss of cementum and dentin[11].

Previous studies to determine the incidence of root resorption have employed diverse assessment criteria. In this study external apical root resorption was defined as any reduction in the radiographic length of the canine from the tip of the crown to the apex of the root, based on the assumption that the crown length will not change during the treatment period.

External root resorption is initiated 14 to 20 days after the orthodontic force is applied and may continue for the duration of force application[11]. It is generally accepted that root resorption associated with orthodontic treatment, commences adjacent to an area of hyalinization and is more likely to occur in cases where the compression is strong and of long duration[12,13,14].

Incidence of root resorption after orthodontic treatment varies from 22% in some studies[15,16]to 100% in others[17,18,19].

Rapid canine retraction by distracting the alveolar bone or the periodontal membrane utilizes light forces for short time,¹ therefor, it has a potential value in minimizing root resorption.

We aim to assess and compare between two rapid canine retraction modalities, alveolar bone distraction *versus* periodontal membrane distraction, *regarding prevalence and intensity of root resorption of the rapidly retracted canines.*

(4) Assessment of dental pulp vitality after RCR:

Postsurgical evaluation of patients who have been subjected to rapid orthodontic tooth movement after a *complete subapical osteotomy*,² demonstrated that teeth within recently osteotomized segments show an overall decreased sensitivity. Teeth that are contiguous to an osteotomy site are in greater jeopardy of becoming devitalized than those that are remote from it[20].

Liou *et al.* [7] reported that seventeen out of twenty six rapidly retracted canines responded negatively to the post-treatment electronic pulp test. All of the teeth were still subjected to orthodontic forces when the post-treatment pulp test was performed.

On the other hand, postsurgical evaluation of teeth that have been subjected to rapid orthodontic movement after a *subtotal osteotomy*, demonstrated that vascular supply of the pulp was not affected. Histological examination revealed a normal pulp tissue structure with an active odontoblastic layer. The functional capacity of the odontoblasts was also confirmed by the deposition of secondary dentin as demonstrated with fluorescent labeling[20]. In addition, a recent clinical study showed that pulp vitality

¹ See section 2.5 for more details.

² See section 2.3 for a detailed description *complete subapical osteotomy* and *subtotal osteotomy*.

was not affected after performing a corticotomy-assisted rapid orthodontic movement[24].

Gazelius *et al.* [125] (1986) first described the use of laser Doppler flowmetry (LDF) for human teeth to study blood flow of the pulp. They correlated between the flowmeter readings taken from incisor teeth with vital pulp tissue and the heart beat using an electrocardiogram, thus proving the ability to record the pulsatile blood flow of the pulp.

Kim *et al.* [126] (1990) compared dental pulp blood flow in dog canine teeth determined by LDF simultaneously with the 133Xenon washout method. The laser Doppler measurements of norepinephrine-induced changes in their experiment correlated significantly with the changes measured by the 133Xenon washout method when analyzed by linear regression. This experiment verified the validity of the LDF as a valuable means to assess the dental pulp blood flow, which accurately represents tooth vitality.

We aim to assess and compare between two rapid canine retraction modalities, alveolar bone distraction *versus* periodontal membrane distraction, *regarding the canines pulp vitality after rapidly retracting them.*

(5) Assessment of periodontal health after RCR:

It has been reported that healthy sites with shallow gingival sulcus may loose approximately 0.5 mm of clinical attachment subsequent to periodontal surgical therapy[21,22,23].

On the other hand, Gantes *et al.* [24] investigated the effects on the periodontium following corticotomy-facilitated orthodontics. The results showed that the corticotomy procedure caused minimal changes in the periodontal attachment apparatus.

We aim to assess and compare between two rapid canine retraction modalities, alveolar bone distraction *versus* periodontal membrane distraction, *regarding periodontal health of the rapidly retracted canines.*

(6) Assessment of prevalence, intensity, and duration of pain or discomfort perception associated with RCR:

Pain or discomfort after activation of orthodontic appliances is a common experience among orthodontic patients.

Burstone[25] identified an immediate and delayed pain responses: The former being related to the initial compression of the periodontal ligament; and the latter, which commences a few hours later, produced by a large range of force values and representing *hyperalgesia* of the ligament. Prostaglandins have been shown to cause hyperalgesia[26,27], which is an increased sensitivity to noxious agents as histamine, bradykinin, serotonin. Acetylcholine, and substance P[28]. Clinical experience and recent research data indicate that patients may adapt to continuous pain and discomfort with the progression of treatment as the sensations cease or at least disappear from their focus of attention[29,30,31].

We aim to assess and compare between two rapid canine retraction modalities, alveolar bone distraction *versus* periodontal membrane distraction, *regarding prevalence, intensity, and duration of pain or discomfort perception associated with rapid canine retraction.*

2. Rapid Tooth Movement:

2.1. Introduction:

In this dissertation I will attempt to blend the central topics of rapid tooth movement, both basic and applied, with the theoretical and speculative. Experience tells us it's far more rewarding to set the pace than to follow it, therefore, it's hoped that my approach will adequately cover the factual material, while permitting at the same time discussion of the uncertainties that remain in the field in a way that may contribute to the development of an enthusiastic professional clairvoyance, and possible directions for the future.

The orthodontist who has only a cursory, tangential interest in rapid tooth movement should find this study a stepping-stone into a fascinating subject. For those already grounded in the fundamentals, it might serve as a useful review to tie together the disparate literature related to this topic.

2.2. Historical review:

One does not arrive at fundamental laws and principles as a function of what is already known. Such laws and principles do not merely explain, they illuminate. They do not merely add to what we know, they create a new space where knowing can occur.
Werner Erhard*²

As an overview of a broad subject, the content of this review must necessarily be limited in scope and depth. The selection of subject matter was neither capricious nor exclusionary, omission of findings or concepts does not imply a value judgment. Simply, the abundance of source material greatly exceeded the space available.

*² ERHARD, Werner (Born 1935), U.S. entrepreneur, Started as a salesman and later established the Erhard Seminar Training, Inc. in 1971.

The purpose of this review is to embody pertinent knowledge from most of the contributing disciplines, combining enough facts with sufficient theory to proffer undergoing this clinical investigation.

The concept of achieving rapid tooth movement by weakening the alveolar bone utilizing an osteotomy or a corticotomy is not new. In 1896 Talbot[4] wrote of his many years' experience with a method of weakening the bone to facilitate orthodontic treatment. He removed alveolar bone in the area where the teeth were to be repositioned, retaining a lamellar segment to preserve the periodontal membrane. He described the alignment of teeth, the uprighting of protruding teeth, with interdental spaces, and the correction of teeth rotations.

Skogsborg[32] (1926) employed a weakening of the interradicular septa to avoid relapse after orthodontic treatment.

It was not, however, until Bichlmayr[33] (1931) used the method that bone weakening came into widespread use. In an Angle Class II malocclusion with dental protrusion and open bite, he carried out the movement of the teeth after extracting first premolars. A wedge-shaped bone resection on the alveolar process lingual to the anterior teeth was accomplished to facilitate retraction and alignment. The time required to accomplish the desired movement with orthodontic treatment was several months, after which retention was used. Bichlmayr[34,35] (1942) recommended a similar procedure on the buccal aspect of the alveolar ridge to expand a narrow maxilla.

Spanier[36] (1932) developed Bichlmayr's technique to a point at which it demonstrated promise as a means to augment orthodontics, but Schönwald[37] (1934)

viewed the method as only a means of preventing relapse in adults treated orthodontically.

Neumann[38] (1955) modified the palatal wedge-shaped osteotomy by introducing interdental *partial osteotomy* to facilitate the closure of large anterior spaces.

Corticotomy, a technique described by Köle[39] (1958), necessitates cutting through both the buccal and palatal alveolar cortical bone surfaces. The corticotomy is not extended through cancellous bone, thus preventing damage to the roots and preserving adequate blood supply to the individual segments. According to Köle[40] (1959), the cortical bone presents the greatest resistance to orthodontic movement. If the cortical bone is sectioned, individual teeth can be repositioned readily because the cancellous bone is more easily resorbed through the application of orthodontic forces. Köle's method of corticotomy was adopted without alteration by Horvath and Rehak[44] (1961), by Dal Pont[41,42] (1963, 1965), and by Edlan and Subrtova [43] (1965, 1967).

Byloff[45] (1967) described comparative histologic findings of adult orthodontic cases treated with and without corticotomy. In 1967, he also described clinical and histologic results of treatment with activator plates with and without corticotomy in adults[46].

Subrtova *et al.* [47,48] (1968, 1970) described the correction of the upper dental arch anomalies in Class II by means of corticotomy. He also described the complications of corticotomy procedure¹.

Converse and Horowitz[49] (1969) used corticotomy to achieve rapid palatal expansion in concert with orthodontic therapy. They excised cortical bone on the

¹ See section 4.2 for more details.

buccal and palatal alveolus below the root apices to facilitate palatal expansion. Bell and Condit[50] (1970) used the combination of corticotomy and orthodontic treatment in the adjustment of the canine after an anterior subapical osteotomy. A rotation of the canine is often necessary when the anterior maxillary dentoalveolar segment is repositioned superiorly and posteriorly. If the bone adjacent to the canine is altered, the canine can be aligned with the aid of elastic traction.

Tenenbaum[51] (1970) described the corticotomy surgical procedure for orthodontic purposes.

Isiksal[52] (1972), from Istanbul University, described the treatment of maxillary protrusion with diastema utilizing corticotomy in conjunction with orthodontic treatment.

Machtens *et al.* [53] (1972), utilized corticotomy as supporting therapy in adult orthodontic cases.

Subrtova and Subrt [54] (1974), corrected reversed anterior bite utilizing corticotomy in combination with orthodontic treatment.

Duker[55] (1975, 1976), described the experimental procedures on beagle dogs to show that groups of teeth can be rearranged by orthodontic appliances, within few days, when bone is weakened by corticotomy. He also described the histologic findings of his studies on rapid dental movements in animals following corticotomy. He concluded that rapid movement did not damage the vascular supply of the dental pulpal tissues. In addition, he reported that if the marginal bone is not impinged upon by the osteotomy saw, only vascular changes in the free gingival mucosa indicate slight reactions of the periodontal membrane.

Aboul-Azm[56] (1977), from Alexandria University, evaluated the utilization of anterior maxillary corticotomy as a line of treatment for maxillary protrusion.

Generson *et al.* [57] (1978), described treatment of anterior dentoalveolar open bite using corticotomy. He concluded that the treatment time was short and the result was stable.

Itoh *et al.* [58] (1981) and Nakanishi[59] (1982), studied experimental tooth movement with osteotomy and corticotomy.

Tuinzin[60] (1986), described the surgical aspects of corticotomy procedure for orthodontic treatment.

Anholm *et al.* [61] (1986), reported successful correction of severe adult malocclusion in several patients treated with the corticotomy procedure.

Kawai *et al.* [62] (1990), reported that corticotomy of the distal part of the mandibular second molar shortens the uprighting time of the mesially tilted mandibular second molar regardless of third molar extraction.

Kerdvongbundit[63] (1990), described the *corticotomy-facilitated orthodontic* procedure. He emphasized its advantages and claimed that the teeth are more stable after this type of treatment, may be due to less disturbance of the periodontal ligament by osteoclastic activity and callus formation which leads to greater stability.

Benech *et al.* [64] (1992), reported correction of two cases having Angle Class II division 1 utilizing multiple alveolar corticotomies, repositioning of alveolar basis and maxillary expansion along orthodontic treatment.

Kawakami *et al.* [65] (1996), reported on the histologic periodontal membrane changes following retraction of the maxillary anterior bone segment after corticotomy.

They demonstrated that point A showed more pronounced retraction in the corticotomy group when compared to the untreated control group.

Liou *et al.* [7] (1998), reported on rapid canine retraction through distraction of the periodontal ligament after minor surgical scoring of the interseptal bone at the time of the first premolar extraction. They concluded that periodontal ligament could be rapidly distracted without complications and that orthodontic tooth movement through distracting the periodontal ligament cannot be emulated by current conventional orthodontic concepts and methods.

2.3. Rapid tooth movement in animals via complete subapical osteotomy versus subtotal subapical osteotomies :

2.3.1. Complete subapical osteotomy:

Weakening of the alveolar bone, to achieve rapid tooth movement, by complete subapical osteotomies of the alveolar ridge consists of two components: a *horizontal osteotomy* separating the dental segment from the basal bone and a *vertical osteotomy* that is usually placed between the teeth in the interradicular bone. Merrill and Pedersen preferred interdental spaces wider than 2mm when performing a vertical osteotomy to prevent damaging the adjacent periodontium[20]. Surgical encroachment on the root can damage the cementum, dentin, and in rare cases, the pulp. To avoid destruction of the periodontal membrane and subsequent tooth loss, the lamina dura of adjacent teeth should not be injured during surgery[20]. Hofer recommended tooth extraction one month prior to interdental surgery to obtain a wide enough interdental osseous ridge at the planned vertical osteotomy site[66].

Single tooth complete subapical osteotomies also can endanger the blood supply to the bone, periodontal membrane, and teeth, leading to unfavorable healing and postsurgical complications like osseous pocket formation, root resorption, and pulp necrosis[20].

2.3.2. Subtotal subapical osteotomies:

The subtotal osteotomies combine a *horizontal subapical osteotomy* and a *partial vertical osteotomy in concert with a corticotomy* (figure 2-1). Dental structures that may be injured during a complete vertical osteotomy are at less risk with a partial vertical osteotomy. Not unlike the complete subapical osteotomy, horizontal osteotomy must have sufficient distance maintained away from the root apices to protect the vascular supply to the dental segment[20].

In animal studies subtotal osteotomies did not affect the vascular supply of the dental pulp. Histological examination reveals a normal tissue structure with an active odontoblastic layer. The functional capacity of the odontoblasts is also confirmed by the deposition of secondary dentin as demonstrated with fluorescent labeling[20].

In contrast to the complete subapical osteotomy in which the entire dento-osseous segment is mobilized, an osseous junction remains after the subtotal osteotomy. During activation of the distraction appliance, the osseous junction will gradually be resorbed which makes the displacement of the partially osteotomized segments possible. In a period of four to ten days a visible loosening between the osseous interfaces occurs, after which movement proceeds relatively easily and rapidly, approximately 0.5 to 1.0 mm per day[20].

An early appearance of *osteoclasts* during orthodontic movement has been shown to cause *resorption*. The resorption occurs in the marrow spaces of the spongiosa when the interalveolar septum is relatively wide (figure 2-2 a). In the narrow interalveolar septum, however, where there is not enough space to unite the palatal and vestibular corticotomies, resorption occurs at the expense of the adjacent periodontium (figure 2-2 b).

In addition, a second and more rapid means of facilitating severance of the interalveolar septum is by the production of *microfractures* in areas under strain by orthodontic or distraction forces. In the wide interalveolar septum, microfractures occur between the vestibular and palatal corticotomies (figure 2-3 a), and in the narrow interalveolar septum microfractures run indirectly via adjacent periodontal spaces (figure 2-3 b).

Both processes, *osteoclast-induced resorption* and *microfractures*, are often seen side by side interposed between vascular connective tissue.

2.4. Results of animal experiments analyzing possible injuries due to osteotomy in the alveolar bone[20]:

Even with the development of precision bone-sectioning instruments, damage to the periodontium cannot be always avoided. If encroachment upon the periodontal membrane should occur, depending on the depth of injury, the alveolar bone, periodontal membrane, cementum, dentin, and pulp may be affected.

An experiment was designed to observe the repair of the periodontal membrane and dental tissues in beagle dogs after an osteotomy. The repair process that occurred in the pulp, dentin, cementum, periodontal membrane, and lamina dura were monitored with

fluorescent dyes. The technique proved itself particularly useful in the study of hard and soft tissue labeling because of the sharp division of the individual fluorochromes.

In order to examine the effect of surgery on the interdental septum and root apices, which cannot be observed directly during the operation, bone cuts were made with an oscillating saw in the upper and lower jaws of the dogs. To simulate all possible injuries to the periodontal membrane and teeth during alveolar osteotomies, the osteotomies were extended at various angles and depths.

2.4.1. Injuries to the periodontal membrane:

Superficial osteotomies that extended to the periodontal membrane but did not reach the hard dental tissues healed completely without discernible damage to the periodontium. Regeneration of the alveolar wall, apposition of cementum, and anchorage of new periodontal fibers were demonstrated by fluorescent labeling. It was concluded that ideal healing usually occurs in the middle and apical thirds of the root when injuries to the periodontal membrane occur.

2.4.2. Injuries to the cementum and dentin:

When the osteotomy extends beyond the periodontal membrane, into the cementum and dentin, complete healing is no longer possible. Repair efforts bring about a partial healing with functionally favorable results. A dentin defect often remains partially filled with bone and callus. Between the tooth and bone a space remains in communication with the periodontal ligament. Through the regeneration of periodontal fibers, a functional adjustment takes place in the area of injury. The fibers orient themselves between the osseous island and the dentin surface where the axial stresses on the tooth can be absorbed by tension. Anchorage of the periodontal fibers to dentin is

greatly facilitated by a secondary layer of cementum. The cementum layer is usually uniformly thin with superficial perforations into dentin.

More penetrating injuries that extend close to the pulp are covered with a thick layer of cementum, leading to a reduction in the size of the pulp cavity.

2.4.3. Injuries to the pulp:

If the osteotomy enters the pulp, formation of secondary dentin occurs. Initially a poorly structured vascularized hard substance is deposited within the pulp, later, it develops into a lamellar stratification. The void in the pulp chamber is gradually filled by deposition of reparative dentin, which forms a bridge across the exposed pulp.

The vascularization of the pulp is minimally affected by a deep osteotomy or even after a complete apicoectomy.

When the continuity of the root apex is disturbed, the coronal tooth fragment may resume normal function. After rounding off the sharp edges of dentin, a new bony alveolar fundus forms that is separated from the severed tooth remnant by an intact periodontal membrane. The remaining apical segment remains dormant, and the coronal fragment becomes partially occluded by secondary dentin, cementum, and bone.

In the light of these animal experiments, favorable repair of periodontal membrane and dentin becomes obvious. Even though complete restoration is not always achieved, healing is to be expected with functional adjustments in the periodontal membrane. Optimal healing appears to occur in the middle and the apical thirds of the roots with the resumption of normal function. Osteotomies in the cervical third, however, usually initiate bone loss of the alveolar ridge, which must be considered as a limitation to osteotomy in this area. This explains the importance of performing a *subtotal*

osteotomy with partial vertical osteotomy in conjunction with corticotomy near the cervical third rather than a complete vertical osteotomy as in the complete *subapical osteotomies*.

2.5. Discussion of rapid tooth movement with subtotal osteotomy:

The subtotal osteotomy can be problematic when the necessary amount of bone is not removed at the time of surgery. If an osteotomy is not extended far enough into the interalveolar septum, a large section of bone may remain, minimizing postsurgical rapid orthodontic movement. When insufficient bone is removed from the interdental corticotomy site, displacement of the dental segment may be possible but the majority of the movement occurs within the dental alveolus.

The subtotal osteotomy in concert with orthodontic movement is different from purely orthodontic movement of teeth. Orthodontic tooth movement occurs principally within the dental alveolus, but with subtotal osteotomy, concomitant orthodontic movement occurs at the osseous interfaces.

An orthodontic force of approximately 75 to 200 g is necessary to initiate movement of the osteotomized segment. The second phase of actual segment displacement can be over several days with orthodontic forces under 100 g. Both the initiation and the maintenance of movement are within the scope of contemporary orthodontics. Maximum forces above 100 g were necessary only for short periods for the severance of the interalveolar septum to initiate rapid tooth movement[20].

Compared to the large forces that must be transferred to the periodontium to rupture the midpalatal suture, the periodontal strain with the subtotal osteotomy is slight[20].

Orthodontic force applied at the crown level of the teeth leads, within the confines of periodontal tooth mobility, to a slight tilting of the tooth in the alveolus. As pressure-tension zones are produced, the appearance of osteoclasts at the pressure side of the alveolar bone resembles that which occurs in conservative orthodontic movement.

Further more, the danger of local osteonecrosis exists because of the employment of unphysiologic forces. Initially, the periodontal membrane will demonstrate areas relatively deficient in cells, indicating early hyalinization. Necrosis in the form of hyalinization cannot always be avoided during orthodontic movement of teeth, but the degenerative process can be reversed if the orthodontic force duration is short. The orthodontic force initially needed to loosen the osteotomized segment after subtotal osteotomy gradually decrease, relieving the strain on the periodontal membrane.

In addition to the generation of pressure under the influence of orthodontic force, tensile forces also arise in the fibers of the periodontal membrane. During orthodontic movement, osteoblasts appear along the lines of tension, aiding in the production of bone. The osteoblastic activity in the periodontal membrane, induced by tension, plays a subordinate role in the subtotal osteotomy because of the short duration of the treatment.

The amount of pressure and tension developed in the periodontal membrane are codetermined by the extent of the subtotal osteotomy and the applied orthodontic forces. Here, analogous to conservative orthodontic movement, resorption proceeds by one of two mechanisms: direct "taking place in the periodontal membrane" and indirect "beginning in the marrow spaces". Active bone resorption in the marrow spaces takes place during various orthodontic movements. In wide interalveolar septa, resorption occurs as a continuation of the buccal and palatal corticotomies. A narrow interalveolar

septum resorbs in the direction of the adjacent periodontal membrane. Byloff-Clar demonstrated that after weakening of the cortical bone, the marginal damage due to the combined surgical-orthodontic treatment is only minimal[20]. If, however, the alveolar wall is damaged during the movement of the osteotomized segment, then bone repair and the formation of a new periodontal membrane will begin during the retention phase of the orthodontic treatment. The healing and reorientation of periodontal fibers is achieved only after an extended time.

In addition to the subtotal osteotomy, microfractures produce a rapid loosening of the partially osteotomized segment. After subtotal osteotomy, relatively low orthodontic force magnitudes are sufficient to fracture the remaining osseous junction. The lines of fracture run parallel to the resorption fronts, relieving periodontal stresses. If the subtotal osteotomy is not extended sufficiently, the activation of orthodontic forces may not be adequate to loosen the osteotomized segments, and resorption of the dental alveolus will occur. If, however, excessive orthodontic force is applied on the assumption that movement can still be effected, the danger of permanent periodontal damage must not be underestimated.

Reactions of the pulp to orthodontic treatment are described by many authors like Oppenheim[2]. The maintenance of blood supply after segmental osteotomies is dependent on the surgical technique. The extent of the gingival incision and the distance of the horizontal osteotomy from the root apices are decisive factors that influence the blood supply to the segment. The subtotal osteotomy with rapid orthodontics, compared with complete subapical osteotomy and repositioning, has the advantage of preserving a greater blood supply to the dentoalveolus. The partially osteotomized segment remains

attached to the alveolar process via the soft tissue pedicle and incompletely sectioned bone. Since the orthodontic movement occurs so slowly, simultaneous vascular regeneration can occur, protecting the vitality of the pulp.

The superficial resorption of cementum, which can occur in varying degrees during orthodontic treatments, has not been observed after subtotal osteotomy. There seems to be direct connection between the force and duration of movement and the effect on dental tissues. For example, one need not anticipate substantial defects in the cementum or dentin with low orthodontic forces or with short duration of treatment. Moreover, resorption lacunae in cementum heal completely during the orthodontic retention phase, with the apposition of cementum and the formation of new periodontal fibers.

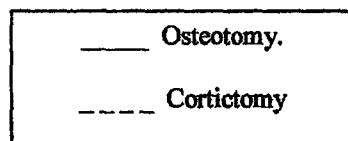
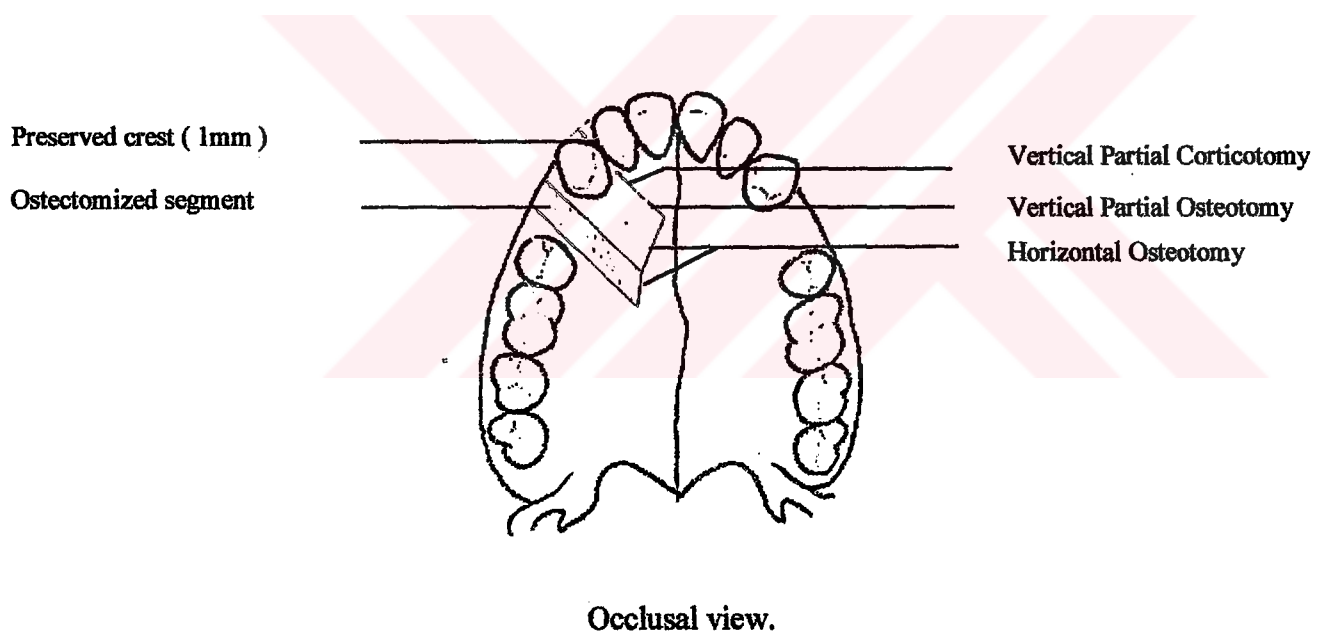
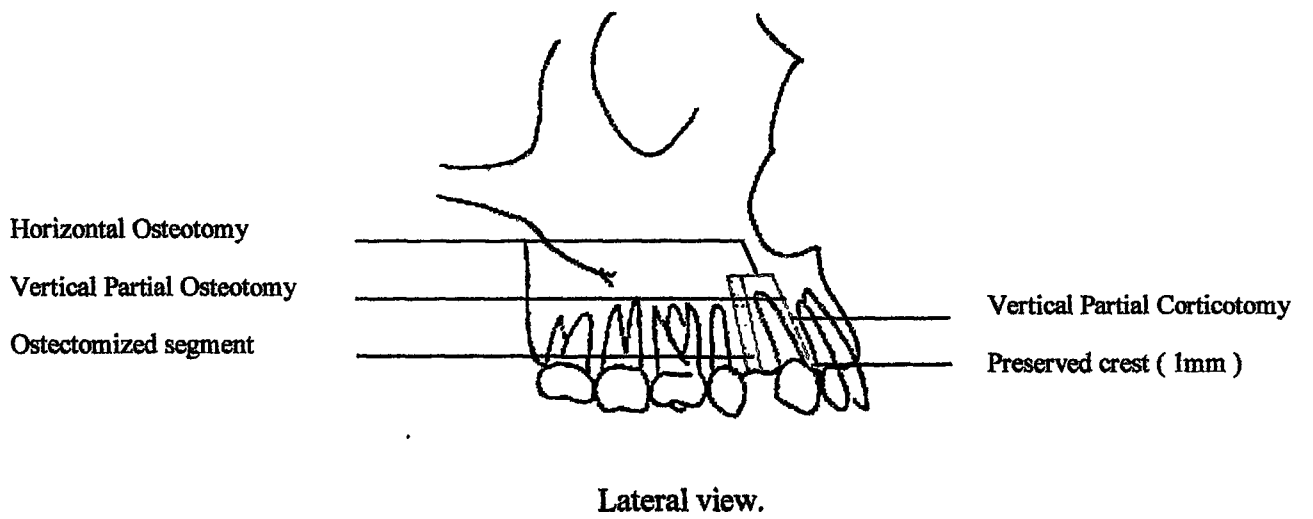
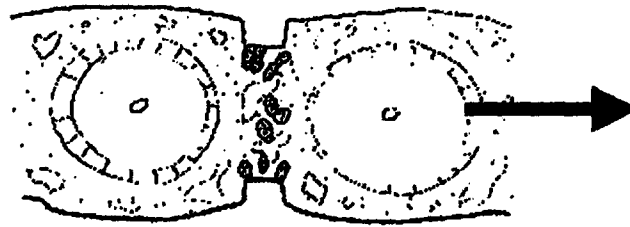
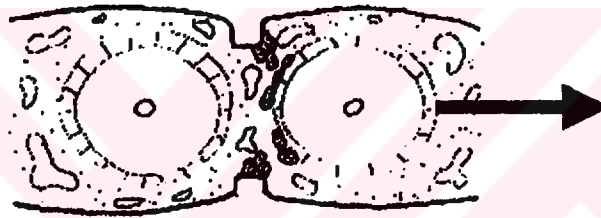


Fig.2-1: Subtotal Subapical Osteotomy design.



- A -

Wide interdental space: Severance of the remaining bone attachment between the two segments by bone resorption running directly through spongiosa.

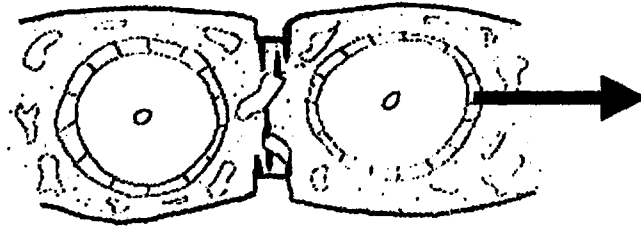


- B -

Narrow interdental space: Severance of the remaining bone attachment between the two segments by bone resorption running indirectly through periodontium.

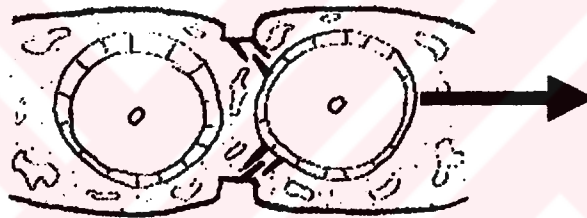
N.B. The arrows indicate the distraction force vector.

Fig.2-2: Patterns of bone resorption induced by the fibroclasts.



- A -

Wide interdental space: Severance of the remaining bone attachment between the two segments by microfractures running directly through spongiosa.



- B -

Narrow interdental space: Severance of the remaining bone attachment between the two segments by microfractures running indirectly through periodontium.

N.B. The arrows indicate the distraction force vector.

Fig.2-3: Patterns of microfractures induced by the mechanical stress of the distraction appliance.

3. Distraction Osteogenesis:

3.1. Introduction:

Gradual distraction of living tissues creates tension-stress that stimulates growth and regeneration. When we apply it to bone, it provides simultaneous rapid bone growth and shaping, *distraction osteogenesis*, and stretching of the surrounding soft tissues, initiating a sequence of adaptive changes termed *distraction histogenesis*.

Distraction osteogenesis can be induced by stretching bone across a growth plate (physeal distraction), stretching bone across a suture (sutural distraction), or stretching of a reparative bone tissue through an osteotomy or corticotomy site (callus distraction). In the later, the technique consists of a surgical intervention in the form of an osteotomy and/or a corticotomy, temporary compression of the bony segments (*latency period*), gradual distraction, and a period of retention for bone consolidation.

3.2. Historical review:

Don't think that years leave us and find us the same.
*Lord Lytton**³

3.2.1. Origins:

Distraction osteogenesis basically came from the field of orthodontics, yet its ramifications took it into such other disciplines as oral, orthognathic, and plastic surgery. Rapid maxillary expansion (RME) was the first documented distraction osteogenesis procedure, it was carried out by stretching the mid-palatal suture by an expansion screw.

In the run-up to the first published account of a patient treated by RME, a number of crude slow expansion techniques may be gleaned from the works of early dental practitioners, but RME was not to spring from such illustrious background. In bustling

³ LYTTON, Edward (1803 - 1873), English novelist, playwright, and political leader. Known for " Last days of Pompeii ".

San Francisco, Emerson C. Angell[67] was the first to place a threaded jackscrew type distraction device between the maxillary premolars of a 14.5-year old girl. Her upper arch was widened one quarter inch rapidly in two weeks by distracting the maxillary bones through the mid-palatal suture[68]. In 1893, Goddard [69] standardized the RME protocol by activating the distraction device twice a day for 3 weeks followed by a stabilization period to allow the deposition of "osseous material" in the resulted gap[70].

3.2.2. In the field of plastic surgery:

Codivilla[71] (1905) introduced the concept of lengthening the lower limb, muscles and associated tissues through distraction osteogenesis. Extensive experience exists in applying distraction osteogenesis for the treatment of congenital and post-traumatic deformities of the extremities as can be seen in the early works of Codivilla(1905), Abott and Saunders[72] (1939), Anderson[73] (1952), Coleman and Noonan[74] (1967), and Ilizarov *et al.* [75] (1980). Over the past 90 years this technique has been developing and has successively received support in different medical fields .

Application of distraction osteogenesis was also reported for elongation of metacarpal bones and phalanges, as was early demonstrated by Metav[76] (1979), and Paneva-Holevich and Yankov[77] (1980).

3.2.3. Mandibular reconstruction:

According to Wassmund, in 1927 Rosenthal performed the first mandibular distraction osteogenesis procedure by using an intra-oral tooth borne appliance that was gradually activated over a period of 1 month[70].

Kazanjian [78] (1937) also performed mandibular distraction osteogenesis by using gradual incremental traction after performing modified L-shaped osteotomies in the corpus. He attached a wire hook to the symphysis, hereby providing direct skeletal fixation to the bone segment to be distracted. Three days post-operatively, a face mask was placed and activated with an elastic band, thereby exerting traction on the chin and gradually pulling the anterior mandibular segment forward. Seventeen days later, the elastic force was removed and occlusal splints which were connected by rigid bars, remained in place for 11 weeks at which time complete consolidation of the jaw had taken place[70].

Crawford [79] (1948) applied gradual incremental traction to the fracture callus of a mandible. The patient presented 2 weeks after a mandibular symphyseal fracture in which a lower central incisor was lost. Before treatment, the mandibular layers had collapsed medially, obliterating the incisor space and creating an apparent crossbite. By using a jackscrew appliance, the fracture callus was stretched over a 3-day period to reestablish the original jaw position, which remained fixed with a sectional occlusal splint[70].

The employment of distraction osteogenesis to mandibular reconstruction was thereafter investigated in animals by Snyder *et al.* [81] (1973), followed by Michieli and Miotti[82] (1976), Kutsevliak and Sukachev[83] (1984), Constantino *et al.* [84] (1990,

1991 and 1993), Karaharju *et al.* [84] (1990 and 1992), Karp *et al.* [85] (1990), Phillips *et al.* [86] (1992), Gantous *et al.* [87] (1994), Komuro *et al.* (1994) [88], Altuna *et al.* [89] (1995), and Rowe *et al.* [90] (1998). Using different animal models, all these investigators demonstrated the feasibility of mandibular reconstruction by distraction osteogenesis.

3.2.4. Maxillary and midfacial reconstruction:

Gradual advancement of the maxilla or midface by distraction osteogenesis provides the possibility of simultaneous expansion of the facial mask, controlled progress of the osteomized segment, and deposition of new bone behind the advancing segment which enhances stability.

Phillips *et al.* [86] (1992) reported on gradual distraction of the zygoma on three dogs. Glat *et al.* [91] (1994) performed a multidimensional distraction of canine zygoma.

Rachmiel *et al.* [92,93] (1993 and 1994) were the first group to perform midface advancement in sheep in an infero-anterior direction to achieve sagittal and vertical corrections. They found that relapse was seven percent after one year follow-up.

Block *et al.* [94] (1994) described preliminary results of maxillary advancement by distraction osteogenesis in .

Cohen *et al.* [95] (1997), Molina *et al.* [96] (1998), Polley *et al.* [97] (1998), and Figueroa *et al.* [98] (1999) described maxillary advancement in cleft patients.

3.2.5. Other applications:

It was suggested by Persing *et al.* [99] (1986), Ilizarov [100] (1989), and Karp [85] (1990) that distraction osteogenesis is applicable for the correction of cranial skeletal disorders.

Persing *et al.* [99] (1986) reported on expansion of the coronal suture in young rabbits. Remmler *et al.* [101] (1992) performed expansion of the cranial vault after craniotomy in adult rabbits. Barone *et al.* [102] (1993) distracted the frontal bone outside the cranial plane. Pittman *et al.* [103] (1997) reported on cranial vault moulding by distraction osteogenesis using transcutaneous activation of implanted magnets. Rinehart *et al.* [104] (1998) used the same technique for cranial vault expansion.

3.3. Bone healing during and after distraction osteogenesis:

Bone healing during and after distraction was investigated by many researchers[9,10]. It was studied using different experimental models like physal distraction of long bones, distraction of long bones after osteotomy or corticotomy, and distraction of mandible after osteotomy or corticotomy. The mode of osteogenesis was essentially similar in all of these models.

Formation of the organic matrix and osteogenesis were studied by radiographic, histologic, and biochemical methods as well as by electron microscopy. Karaharju *et al.* [9] summarize the process in the following sequence:

- *During the initial phase, up to one week of distraction:*

After starting the osteotomy distraction, a radiolucent zone appears in the distraction area. This zone is composed of a heterogenous cell population. Light and electron microscopic studies showed that in addition to fibroblasts and endothelial cells, there were large polymorphic cells with signs of active cell metabolism. Capillary formation starts at this stage too. The collagen bundles are thin and unorganized. Determination of fibrillar collagens shows predominantly the presence of the

heteropolymer type I collagen, which indicates *intramembranous* mode of bone formation[10].

- *After the first week:*

The distraction area starts to organize. The collagen bundles display an orientation according to the tensile force. The central part of the distraction gap is mainly composed of collagen-producing fibroblasts. The capillaries start to appear near the osteotomized bone ends. The center of the gap appears relatively avascular.

- *After two weeks:*

Early bone formation starts by laying down thin osteoid and bone trabeculae in accordance with the organized collagen frame.

- *After three weeks:*

Mineralization of the lengthened segment becomes more advanced. In osteotomy or corticotomy distraction, osteogenesis proceeds centripetally toward the center of the distraction gap.

- *After four weeks:*

Bone formation progresses with an increasing amount of bone lamellae oriented according to the direction of distraction. The central part of distraction area remains essentially the same as long as distraction is continuing. At this stage the proportion of collagen weight to the total matrix protein weight is about 75-88% which is characteristic of mature bone.

- *Union, gap closure, and remodeling:*

In the mandible, a solid union across the distraction gap appears radiographically sixteen weeks after the distraction period. Histologic studies show that up to twenty weeks, the gap was mostly closed. In thirty five weeks, bony union is complete and the

remodelling starts. One year after the distraction, the distracted bone becomes almost identical to the control.

From the previous description, it seems obvious that distraction osteogenesis is a specific way to induce bone formation. The primary inductive factor for cell transformation, collagen synthesis, and bone formation is gradual mechanical distraction.

3.4. Factors influencing osteogenesis during distraction[105]:

The factors which were discussed in the literature and were found to influence the distraction osteogenesis of long bones are summarized as follow:

3.4.1. Surgical factors:

Surgical factors include the surgical technique and the location of bone transection. Ilizarov[100] considered the mere corticotomy to be of first importance for the callus distraction. He attributed great significance to the intactness of the nutrient artery. His resulting demand to preserve the medullar vascular system by the method of corticotomy technically is uncontrollable. The intraoperative verification of the success of the corticotomy is conducted either radiologically by showing a diastasis, or clinically by showing a total instability. Both methods suggest at least a partial destruction of the intramedullary vascular system.

Moreover, Yasui *et al.* [106] were able to prove through microangiography a complete restitution of the intramedullary vessels 10 days after complete osteotomy. Delloye *et al.* [107] showed the lack of distinction between corticotomy and osteotomy concerning the method of bone healing and the amount of the newly formed bone. Numerous authors were able to prove the efficiency of osteotomy for callus distraction. [108,109]. It's important to use a chisel instead of a saw during osteotomy to avoid local

heat-induced damage of the bone ends that might lead to a reduction of the bone regeneration.

3.4.2. Postoperative factors:

The start of distraction, the distraction rate, and the pace of distraction are considered important postoperative factors. Ilizarov[100] and White and Kenright[109,110] indicated the significance of the postoperative latent period before distraction and observed lower quantities of newly formed bone when the latent period had been short or missing altogether.

On the other hand, only Aronson and Shen[111] were able to induce a sufficient callus formation in animals after an immediate postoperative distraction. Nevertheless, applying the results from animal experiments to a clinical use in humans is a very questionable procedure considering the experience with the Wagner technique[112]. This method advertised an immediate start of distraction after bone transsection but did not result in adequate bone regeneration, which necessitated a spongiosa grafting after distraction to fill the bone defects.

Fink *et al.* [105] investigated the radiographic density of the distracted zone to monitor bone formation in that area in 57 patients. They found that longer patent periods led to a slight rise of the density-curve gradient, and improved bone formation after a latent period of more than 8 days compared with a group with a latent period of less than or equal to 8 days.

Various authors reported that a daily distraction of 1mm yielded the best results[107,100,113]. Slower distraction often leads to early ossification of the distraction space. On the other hand, faster distraction (> 1mm/day) coincides with less new bone

formation, most likely attributable to microangiographically visible tearing of endosteal and periosteal vessels[100.113.106].

The daily distraction generally should be accomplished in as many steps as possible. Ilizarov[100] was able to prove that the highest bone regeneration was effected by an autodistractor at 60 steps a day and that distraction of the same daily length in one step was followed by the lowest bone formation.

These results led to the general recommendation of starting distraction at a rate of 0.25mm 4 times a day after a 7 day latent period.

3.4.3. Mechanical factors:

The stability and the functional loading of the distracted bones seem to be play an important role in bone formation, which requires a height bending and shearing strength of the distraction appliance.

3.4.4. Patient-related factors:

Paley[114] discovered that the healing index in adults can be as much as twice as high as in children. Fischgrund *et al.* [115] showed that bone formation occurs sooner and more rapidly in patients younger than 20-year old than in patients between 20 to 29-year old. The latter shows higher ossification activity than a group of patients older than 30 years. The patients younger than 20-year old did not differ concerning osteoneogenesis in the 1 to 9-year age and the 10 to 19-year age groups. Similar results were obtained by Fink *et al.* [105]

The local blood supply might have a key function concerning the regionally varying bone-forming processes that have been observed. Brutscher *et al.* [116] attributed the noticeably lessened bone formation in the ventral and medial tibia (during callus

distraction of the shank) to the insubstantial soft tissue covering and the resulting inferior local blood supply of the bone in that area.

3.5. Soft tissues healing during and after distraction osteogenesis:

Since 1951, Dr. Gavriil A. Ilizarov has been engaged in clinical, biological, engineering, and basic science research in orthopedics and traumatology. His work has led to the discovery of a general biologic principle that governs the stimulation of tissue growth and regeneration during distraction. This principle is called the Law of Tension-Stress, which states that tissues subjected to slow, steady traction become metabolically activated, a phenomenon characterized by stimulation of both proliferative and biosynthetic cellular functions. In his classical article (The Tension-Stress Effect on the Genesis and Growth of Tissues, Part I) [100], he described the reactions of soft tissues undergoing elongation by a distraction device, in a series of experiments on canine tibia, as follows:

3.4.1. Connective tissues:

In the connective tissue fascia, endomysium, and perimysium of muscle, adventitia of blood vessels, and perineurium of nerve trunks the collagen fibers were oriented along the vector of tension (figure 3-1 A) as were the cytoplasmic organelles including the granular endoplasmic reticula and the mitochondria (figure 3-1 C). Also the number of fibroblasts increased during distraction and contacts between them multiplied, with dense junctions in many places (figure 3-1 B).

3.4.2. Muscular tissues:

During elongation, under the influence of tension-stress effect, skeletal muscle demonstrated ultrastructural changes in both the energy-supplying and protein-synthesizing systems.

On day fourteen of optimal distraction, the energy-providing mitochondria hypertrophied and displayed an enlarged volume with multiple cristae (figure 3-2 A), especially in sections obtained from the ends of muscle fibers and sarcolemmal regions where actin and myosin myofilaments were being actively synthesized on the polysomes (figure 3-1 C). The functional activity of the nuclei was enhanced, characterized by hypertrophy of their nucleoli and the appearance of deep karyolemmal invaginations (figure 3-1 B).

Muscle growth under the influence of tension-stress occurred not only by myofibrillogenesis in preexisting muscle fibers, but also by the formation of new muscle tissue. Within the newly formed muscle fiber, active formation of myofibrils and sarcomeres took place (figure 3-1 D).

Smooth muscle tissue in the blood vessel walls also grew under the influence of tension-stress effect. Morphologic features common to elongating smooth muscle cells include:

- Biosynthetic activation of smooth muscle cells and an increased number of contacts between them (figure 3-3 A).
- New formation of elastic structures in the arterial walls (figure 3-3 B).
- Longitudinal rather than circular orientation of the smooth muscle cells (figure 3-3 C).

From a functional point of view, muscles affected by skeletal distraction in the same plane adapt with compensatory regeneration and hypertrophy. Moreover, those muscles lying in a different plane, in relation to distraction vector, show persistent evidence of atrophy [132].

3.4.3. Vascular tissues:

New blood vessels formed along the direction of the tension vector. Under optimum conditions of traction, that is at a rate of 0.125 mm every six hours, two types of blood capillaries appeared by day seven (figure 3-4):

- Sinusoidal capillaries characterized by a wide lumen and the presence of openings in the endothelium.
- Transport capillaries characterized by a narrow lumen and a continuous endothelium.

After day twenty one, the growth of newly formed capillaries under the influence of tension overtook the speed of distraction. These newly formed vascular structures anastomosed with the soft-tissue vessels surrounding the distraction zone *via* multiple perforating vessels.

3.4.4. Nervous tissues:

Tissues elongated under the influence of tension-stress effect were accompanied by the development and growth of nerves supplying them.

By day seven of optimal distraction, the elongated axons were partially surrounded by cytoplasmic processes of Schwann cells (figure 3-5 A). Eventually, these processes grew to completely envelope axons and join one another on the same axon (figure 3-5 B). By day twenty one, the schwann cells were lengthened totally covering the

axons forming a myelinic membrane (figure 3-5 D). These changes are similar to embryonic peripheral nerve formation.

3.4.5. Skin reactions:

By day twenty one of optimal distraction, Many mitotic figures were noted in the cells of the basal cell layer (figure 3-6 A). As a result, the number of basal cell layers increased considerably, up to ten layers compared to three to five layers in controls.

Skin appendages also were activated. By day twenty one, the number of hair follicles increased in number and thickness considerably (figure 3-6 C), along with their associated sebaceous and sweat glands (figure 3-6 B). Moreover, the glands, especially sebaceous ones, hypertrophied.

3.5. Distraction appliances:

Distraction appliances are either:

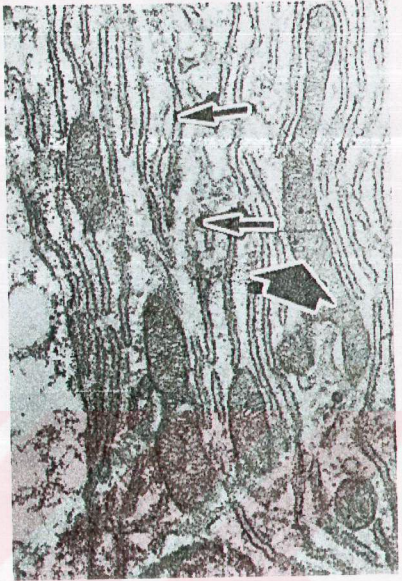
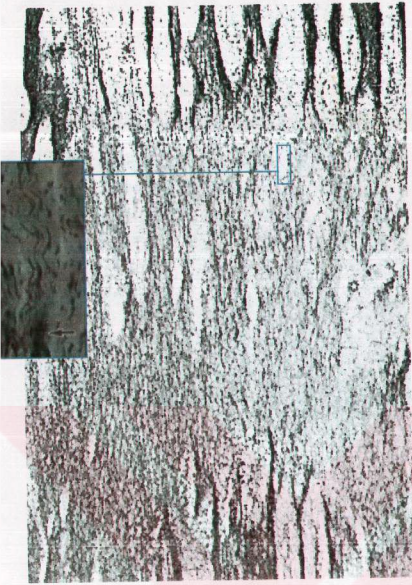
- 1- Extra-oral: which can be activated in a linear unidirectional, bidirectional, and multidirectional modes. In addition, some advanced appliances allow angular manipulations.
- 2- Intra-oral: which are tooth-borne, bone-borne, or hybrid. They can be activated in unidirectional, bidirectional, or multidirectional linear modes.

The extra-oral distraction appliances are simple to attach and easy to manipulate. On the other hand, patients are apprehensive about wearing such bulky external appliances. Moreover, the scarring tissue which results from the transcutaneous fixation pins is esthetically unacceptable.

In this study, we carried out canine retraction through distraction utilizing intraoral, custom-made, tooth-borne, linear unidirectional distraction appliances¹.



¹ See section 5 for more details.



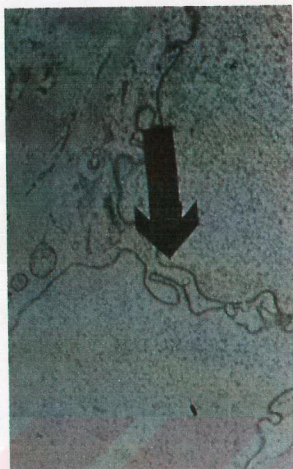
A: The middle of the distraction zone shows longitudinally oriented collagen fibers. Osteoid tissue grows and matures proximally and distally (van Gieson's original magnification X25).

B: Longitudinally oriented fibroblast-like cells in the middle of the distraction zone (van Gieson's original magnification X 160).

C: Elongated mitochondria (large arrow) and endoplasmic reticulum (small arrows), (original magnification X 3000).

N.B. Slides and commentary are taken from reference no. 100.

Fig.3-1: Connective tissues adaptive changes during distraction osteogenesis.



- A: Hypertrophied mitochondria with multiple cristae (arrow), (original magnification X 20 000).
 B: Karyolemmal invaginations charecteristic of enhanced functional activity (arrow), (original magnification X 8000).
 C: Myofilaments synthesisization on the polysomes(arrow), (original magnification X 15000).
 D: Active formation of myofibrils and sarcomeres (arrow), (original magnification X 8000).
 N.B. Slides and commentary are taken from reference no. 100.

Fig.3-2: Skeletal muscle tissue adaptive changes during distraction osteogenesis.



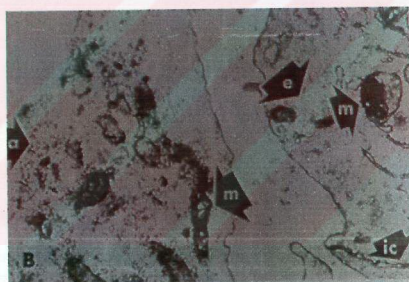
A: Finely dispersed functionally active euchromatin (curved arrow), elastic structures (small arrows), and activated smooth muscle cells (large straight arrows), (original magnification X 15000).

B: Formation of elastic structures (arrows), (original magnification X 8600).

C: Longitudinal orientation of arterial wall smooth muscle cells (original magnification X 500).

N.B. Slides and commentary are taken from reference no. 100.

Fig.3-3: Arterial wall smooth muscle cells adaptive changes during distraction osteogenesis.

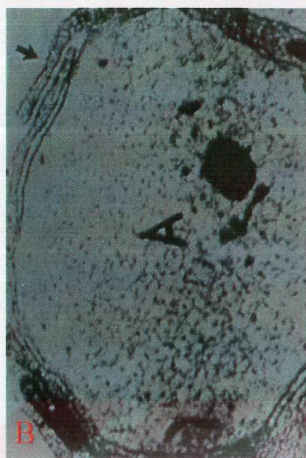
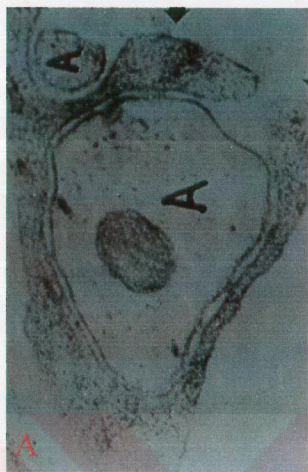


A: New capillary formation with directional cells at their blind ends (original magnification X 500).

B: Some mitochondrial (m) and endotheliocyte (e) damage is observed. Activated smooth muscle cells (a) indicate tissue growth. Increased intercellular contacts (ic) (original magnification X 15 000).

N.B. Slides and commentary are taken from reference no. 100.

Fig.3-4: Vascular tissue adaptive changes during distraction osteogenesis.



A: Axons (A) of the elongated nerves are partially surrounded by Schwann cells (arrows) (original magnification X3000).

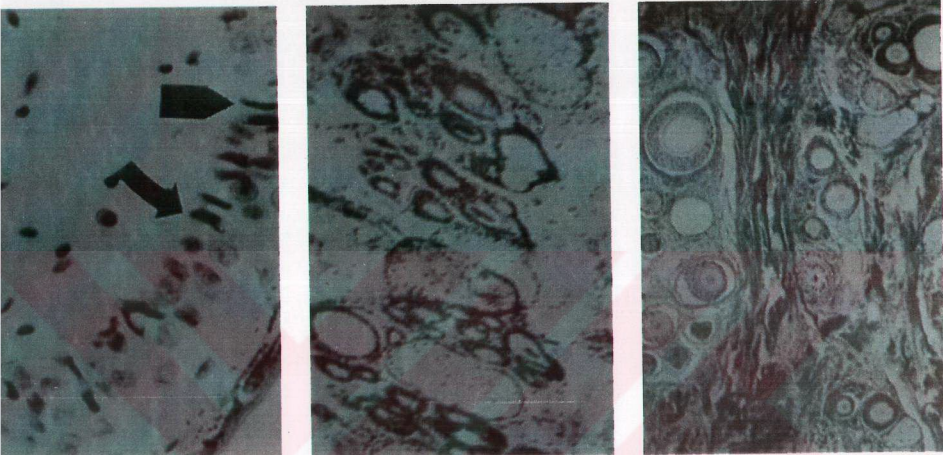
B: Envelopment of axons (A) by Schwann cell (arrow) (original magnification X3000).

C: Spiral envelopment of axon (A) by Schwann cell (arrow) (original magnification X3000).

D: The formation of myelinic membrane (arrow) around an axon (A) (original magnification X3000).

N.B. Slides and commentary are taken from reference no. 100.

Fig.3-5: Elongating nerves sequential adaptive changes during distraction osteogenesis.



A: Elongation of basal cell nuclei (arrows), a sign of hyperplasia (original magnification X 250).

B: Hyperplasia of sebaceous and sweat glands (original magnification X 160).

C: Hyperplasia of hair follicles (original magnification X 160).

N.B. Slides and commentary are taken from reference no. 100.

Fig.3-6: Skin tissue adaptive changes during distraction osteogenesis.

4. Study Design:

4.1. Study subjects " *sample size and inclusion criteria* ":

Seven consecutive orthodontic patients (4 females and 3 males) were admitted to the study on the basis that they were willing to participate and they satisfied the following criteria:

- (1) The patients needed bilateral first premolar extraction and canine retraction in the maxillary dental arch. The patients profile and lip posture were assessed before extraction decision was made.
- (2) There was no relevant medical or dental history that contraindicates the planned orthodontic treatment or the surgical intervention.
- (3) The patients growth was in the post-peak stage. To fulfill this requirement, the selected patients were above fifteen-year old.
- (4) The patients, or parents, signed an informed consent. The patients were informed of the risks related to the surgery. Other forms of orthodontic treatment were also explained and discussed, including no treatment. The patients consented to the rapid canine retraction treatment, which was a clinical research project.

A male patient and a female patient decided to withdraw from the study. Another male patient did not follow the appliance activation protocol. These were excluded from the study. In addition, the records of two female patients were not complete by the time this study was terminated, these two patients were also excluded. Eventually, 1 male and 1 female patients were included in the analysis of this study results.

4.2. Clinical protocol:

Rapid retraction of 8 canines (4 by alveolar bone distraction procedures and 4 by periodontal membrane distraction procedures) were carried out with custom-made, tooth-borne, intra-oral, unidirectional distraction devices utilizing modified jackscrews, which were inserted immediately after a minor surgical intervention and activated three days later. The distraction devices were activated 0.2 mm four times a day (total activation 0.8 mm/day) until desired canine position was reached. The consolidation period lasted for 6 weeks, during which leveling of the incisors was achieved.

4.3. Events schedule:

4.3.1. Screening:

- Comprehensive clinical examination.
- Referrals.
- Upper and lower impressions.
- Upper and lower arch study models analysis.
- Cephalometric analysis I: to evaluate extraction treatment.
- Pantomograph assessment.
- Signing an informed consent.

4.3.2. General procedures:

- Extra-oral and intra-oral photographs.
- Upper arch impressions.
- Construction of the radiographic markers.
- Cephalometric analysis II, with the markers.
- Construction of the radiographic splint.
- Standard periapical radiographs analysis.

4.3.3. Surgical procedure 1:

- Bilateral extraction of upper first premolars.

4.3.4. Appliance fabrication:

- See section 5 for details.

4.3.5. Surgical procedure 2:

- See sections 6.3.a and 6.3.b for details.

4.3.6. Follow-up:

- **During distraction:** the retraction rate, commencement of bone formation, and discomfort prevalence and intensity were assessed.
- **Post-treatment:** after canine retraction, the nature of tooth movement, anchorage loss, progress of bone formation and remodeling, root resorption, pulp vitality, and periodontal health were assessed.

4.4. Methods:

During the retraction procedure and the following retention period, six specific objectives were investigated as follows:

4.4.1. Assessment of and comparison between two RCR techniques: regarding the nature of tooth movement (tipping versus translation), the rate of retraction, and anchorage loss:

- **Nature of retraction (tipping *versus* bodily):**

Lateral cephalometric radiographs were taken before and after retraction. A constructed true horizontal plane (that was drawn at 15° to the sella-nasion plane [SN]) was used as a reference plane against which the inclinations of the right and left canines were measured on the pre-treatment and post-treatment cephalograms (figure 4-2). The

angular measurements were of the anterior angles which were formed by the intersection of the constructed true horizontal and the inclination axis of the canines, which were represented by radiographic markers. Tipping was calculated as follows:

$$\text{Tipping (}^{\circ}\text{)} = T (\text{post-treatment}) - T (\text{pre-treatment}),$$

where T is the anterior angle between the constructed true horizontal and the canine marker extension.

Positive value indicated distal crown tipping, whereas negative value indicated medial crown tipping.

Radiographic markers:

We used 0.032 inch stainless steel wire markers to identify the inclination axis of the right and left canines to overcome their superimposition problem in cephalograms. These markers were oriented vertically and retained in acrylic caps (figure 4-1), which were cemented temporarily to the canines during taking the cephalometric radiographs. *In the right side*, the wire was located medially and its tip was bent medially (figure 4-1 a), while *in the left side* the wire was located distally and its tip was bent distally too (figure 4-1 b), to prevent superimposition of the markers on the cephalograms.

- **Rate of retraction:**

On the same lateral cephalometric radiograms, a constructed true vertical plane (drawn from the sella point at right angle to the constructed true horizontal) was used as a reference plane against which the canine retraction distances were measured on the pre-treatment and post-treatment cephalograms (figure 4-3). The linear measurements included:

- 1- The pre-treatment and post-treatment distance between the medial contact point of the right canine and the constructed true vertical.
- 2- The pre-treatment and post-treatment distance between the distal contact point of the left canine and the constructed true vertical.

The medial contact point of the right canine and the distal contact point of the left canine were represented by the lower end of the vertical part of the radiographic markers.

The rate of retraction was calculated as follows:

$$\text{Retraction rate (mm/day)} = \text{Retraction distance (mm)} / \text{Retraction time (day)},$$

$$\text{Retraction distance (mm)} = C (\text{prè-treatment}) - C (\text{post-tratment}),$$

where: C is the horizontal distance between the constructed true vertical plane and the canine marker.

- **Anchorage loss:**

On the same lateral cephalometric radiograms which were taken before and after retraction, the constructed true vertical line was used as a reference plane (figure 4-4). Using first molar markers (constructed in the same manner as described for the canines), the following linear measurements were taken:

- 1- The pre-treatment and post-treatment distance between the medial contact point of the right first molar and the constructed true vertical.
- 2- The pre-treatment and post-treatment distance between the distal contact point of the left first molar and the constructed true vertical.

The medial contact point of the right first molar and the distal contact point of the left first molar were represented by the lower end of the vertical part of the radiographic markers.

Any increase in the horizontal measurement between the constructed true vertical and the molar marker was considered as anchorage loss, the amount of which was calculated as follow:

$$\text{Anchorage Loss (mm)} = M (\text{post-treatment}) - M (\text{pre-treatment}),$$

where: M is the horizontal measurement between the constructed true vertical plane and the first molar marker.

4.4.2. Assessment of new alveolar bone formation and remodeling after RCR:

A sequence of periapical radiographs of the retracted canines was taken pre-operatively and once every 3 weeks post-operatively for 6 weeks.

A conventional dental X-ray unit was used along with a charge coupled device (CCD) sensor (Radiovisiography, Trophy Radiologie, France) which has 17 X 26 mm image surface (similar to size 0 films). The radiation which penetrates the object, at the exposure time, hits a fluorescent screen, the first layer of the sensor. The resulting light emission is transmitted through a fibre optic layer to the CCD where the light will be converted into electrical signals. These electrical signals go through a central processor to a video screen for instant display. Thereafter, images were stored in a PC computer. Using a special software (from Trophy Radiologie, France)[122] the images were converted from gray scale into a colored scale to reflect the density of various structures including the alveolar bone medial to the retracted canines.

A specific area was selected for the densitometric analysis which was in the middle distance between the canine and lateral incisor roots, 5 mm apical to the canine cementoenamel junction level. This area represents the undifferentiated radiolucent zone which was described in section 3.3. This zone is the last to ossify, and its ossification

indicates the union of the two fragments of the alveolar bone, in case of alveolar bone distraction, and the beginning of bone remodeling in case of periodontal membrane distraction.

The bone density, of the selected area, were then compared during the specified intervals to follow up the progression of bone formation.

4.4.3. Assessment of root resorption during and after RCR:

Periapical radiography utilizing the paralleling technique is an accurate means to investigate root resorption. The essence of the paralleling technique (also called right-angle or long cone technique) is to support the x-ray film parallel to the long axis of the teeth and to direct the central ray of the x-ray beam at right angle to the teeth and the film. This orientation of the film, teeth, and central ray minimizes geometric distortion. In addition, the use of long cone reduces the size of the apparent focal spot resulting in images with less magnification and increased definition.

Radiographic technique:

Standard canine projection demonstrating all of the canine with its periapical area was implemented utilizing the periapical paralleling (long cone) radiography technique. A number 0 film was placed against the palate with its anterior edge at about the middle of the lateral incisor and its long axis parallel with the long axis of the canine. The holding instrument directed the central ray to the center of the film and perpendicular to the plane of the film. The central ray was directed through the canine eminence[123].

Extension cone paralleling instruments (XCP) in conjunction with custom made tooth-borne splint were utilized to be able to have repeatable standard exposures. In addition, a precision rectangular collimating instrument was used to restrict the beam size

at the patient's face to the size of the film, this is believed to provide 50 to 300 percent dose reduction per film[124].

Calculation of apical root resorption:

The apical root resorption per tooth was expressed as follows:

$$\text{Apical Root Resorption (ARR)} = T2 - T1,$$

where: T1=Tooth length before treatment, T2 = Tooth length after treatment (figure 4-11).

Radiographic splint:

Two custom made, tooth-borne radiographic splints were fabricated for each patient (one for the left and one for the right canine) to provide repeatable standard exposures before and after retraction to enable us to detect any change in the root length.

The splint was designed to optimize the following criteria:

- 1- *Image field*: the projection should demonstrate all of the canine with its periapical area, in the midline of the radiograph. The medial contact area should be opened (figure 4-7).
- 2- *Film placement*: A No.0 film should be oriented with its anterior edge at about the middle of the lateral incisor and its long axis parallel with the long axis of the canine (figure 4-8 and 4-9).
- 3- *Projection of central ray*: the central ray should be directed to the center of and perpendicular to the plane of the film. It should also be perpendicular to the canine long axis (figure 4-8 and 4-9).
- 4- *Point of entry*: the central ray should be directed through the canine eminence and the point of entry should be at about the intersection of the distal and inferior borders of the ala of the nose (figure 4-10 b).

5- *Image magnification*: should be kept minimal and constant by placing the film as close to the tooth as practical and by keeping the distance between the x-ray source and the canine constant (figure 4-10 a).

For further details about the x-ray splint fabrication, see figures 4-5 and 4-6.

4.4.4. Assessment of dental pulp vitality after RCR:

Pre-treatment and post-treatment electronic pulp test readings were obtained from the retracted canines to assess their vitality.

4.4.5 Assessment of periodontal health after RCR:

Pre-treatment and post-treatment *probing pocket depths (PPD)*, *probing attachment levels (PAL)*, and *crestal bone height (CBH)* measures were recorded from six reference points around the retracted canines and the second premolars distal to them, see details below. All measurements were made by the same examiner.

Using a standard graduated periodontal probe which has a 0.5 mm tip in diameter, recordings to the nearest 0.5 mm were taken from the mesiobuccal, midbuccal, distobuccal, mesiopalatal, midpalatal, and distopalatal sites around each retracted canine and the second premolar distal to it. An acrylic cap with the reference points mentioned above was temporarily cemented on the canine (figure 4-13), and the followings measurements were recorded from each reference point (figure 4-12):

Probing pocket depth was measured from the gingival margin to the bottom of the pocket.

Probing attachment level was measured from the acrylic cap margin to the bottom of the pocket.

Crestal bone height was measured from the acrylic cap margin to the tip of the crestal bone (under local anesthesia).

4.4.6 Assessment of prevalence, intensity, and duration of pain or discomfort perception associated with rapid canine retraction treatment:

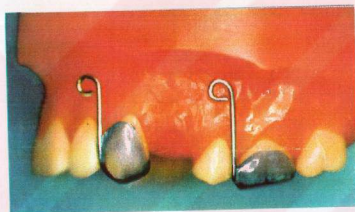
Discomfort index cards (figure 4-14) were administered to the patients which consisted of seven separate visual analogue scales (VAS)[128], each being 15 cm in length and anchored by both happy and sad faces and extreme descriptor terminology. Each patient was requested to make a small vertical line that indicate their feelings on the given time being rated. The pain score for each VAS was the distance in millimeters from the left side of the line to the vertical mark that was made by the patient. The VAS is a valid and reliable means in this regard as indicated in the literature[129].

The discomfort index card was administered to the patients after extraction, before the insertion of the retraction appliance, to have this pain score as the control. After the subtotal osteotomy surgery and the insertion of the distraction appliance, each patient was instructed to complete the discomfort index cards on every day basis until the end of retraction procedures.



- a -

Right side: the markers are placed in the distal aspect and their tips are bent distally.

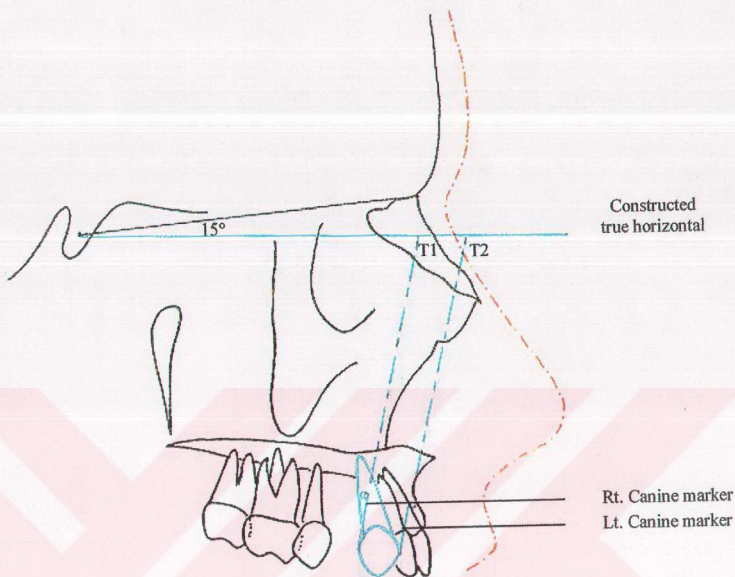


- b -

Left side: the markers are placed in the medial aspect and their tips are bent medially.

N.B. The acrylic cap design in the right side differs than that of the left side for easier identification.

Fig.4-1: Cephalometric radiographic markers.



$$\text{Tipping } (^{\circ}) = T (\text{post-treatment}) - T (\text{pre-treatment})$$

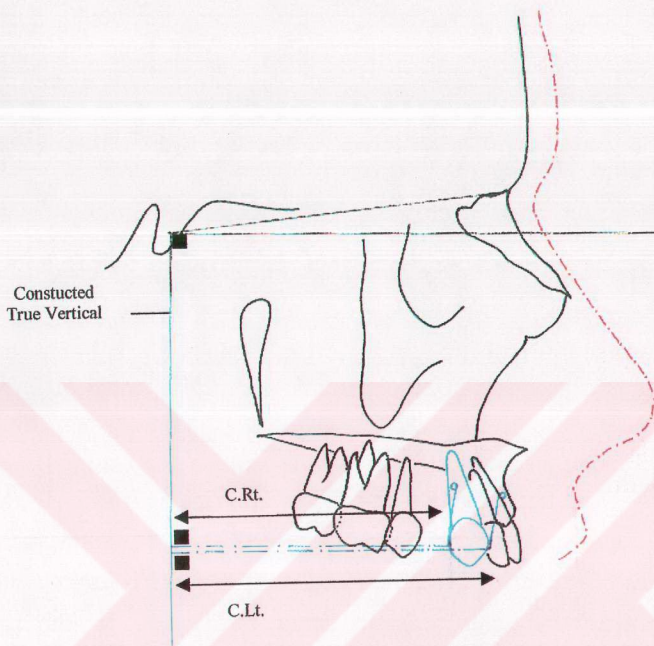
Where T is the angle (°) between the constructed true horizontal and the canine marker.

N.B.: +ve value indicates distal crown tipping, whereas -ve value indicates medial crown tipping.

T1: The angle (°) between the constructed true horizontal and the right canine marker.

T2: The angle (°) between the constructed true horizontal and the left canine marker.

Fig.4-2: Tipping measurement.

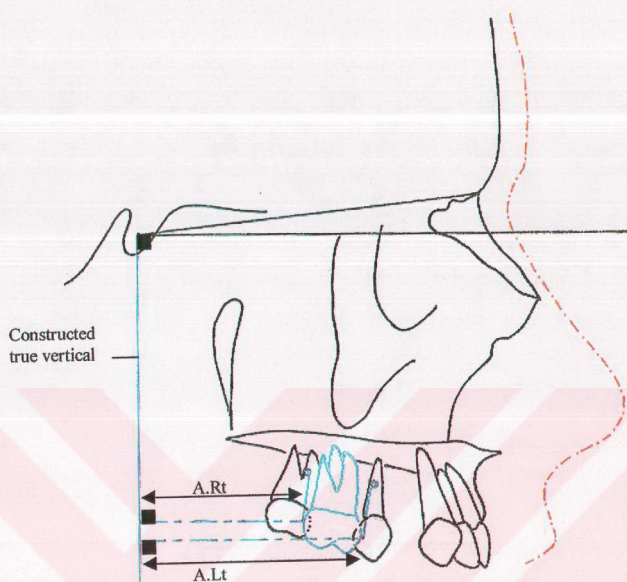


$$\text{Retraction distance} = C (\text{pre-treatment}) / C (\text{post-treatment}),$$

where C is the horizontal distance between the constructed true vertical and the canine marker

C.Rt.: Horizontal distance (mm) between the constructed true vertical and the right canine marker.
C.Lt.: Horizontal distance (mm) between the constructed true vertical and the left canine marker.

Fig.4-3: Retraction distance measurement.

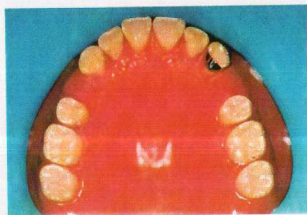


$$\text{Anchorage Loss (mm)} = A(\text{post-treatment}) - A(\text{pre-treatment}).$$

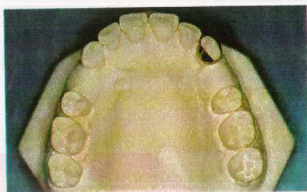
Where A is the horizontal distance between the constructed true vertical and the molar marker

A.Rt.: Horizontal distance (mm) between the constructed true vertical and the right molar marker.
 A.Lt.: Horizontal distance (mm) between the constructed true vertical and the left molar marker.

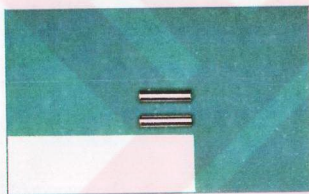
Fig.4-4: Anchorage loss measurement.



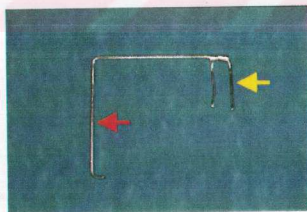
A: Fitting the canine band and then taking an alginate impression with the band in.



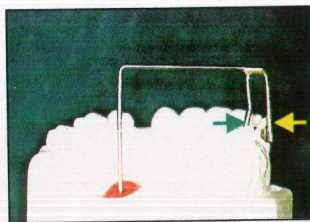
B: Pouring the impression with plaster to have the working model.



C: Two pieces of 7 mm long 0,047" stainless steel tube are cut.

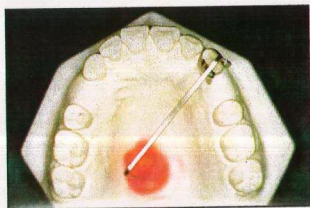


D: Film holder analogue: Resembles the film holder and is used to hold the tubes during soldering them to the canine band. The labial wire (Yellow arrow) should be parallel to the film axis (red arrow).

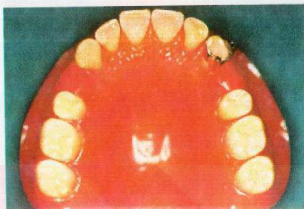


E: Tubes placement, lateral view: one tube (yellow arrow) is placed labially parallel to the long axis of the canine, and the other (green arrow) is placed palatally in close approximation with the canine band.

Fig.4-5: Radiographic splint fabrication.



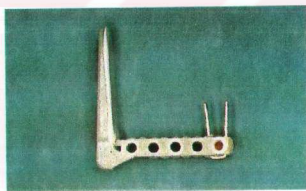
F: Tubes placement, occlusal view: one tube is placed labially parallel to the long axis of the canine, and the other is placed palatally in close approximation with the canine band.



G: The two tubes are soldered to the canine band, Occlusal view.



H: The tooth-borne part of the splint is fitted to the canine, lateral view.

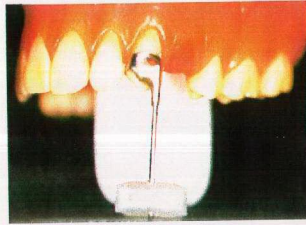


I: The film holder-borne part of the splint is made of 1.1 mm stainless steel wire and is fitted to the film holder.
N.B. The labial arm should be parallel to the film axis.



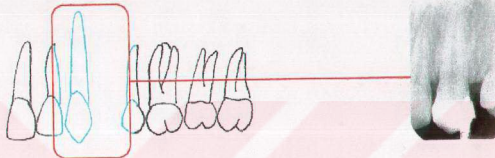
J: The two parts of the splint are assembled. lateral view.

Fig.4-5: Radiographic splint fabrication, continued.



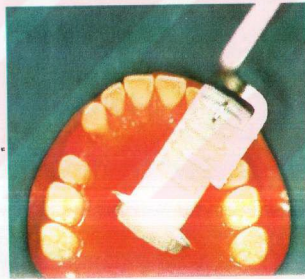
- a -

The radiographic splint is assembled and fitted to the canine, lateral view.



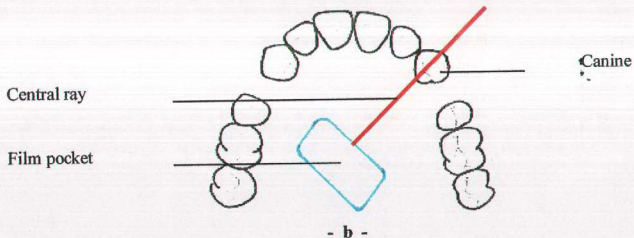
- b -

Fig.4-6: The radiographic splint, image field.



- a -

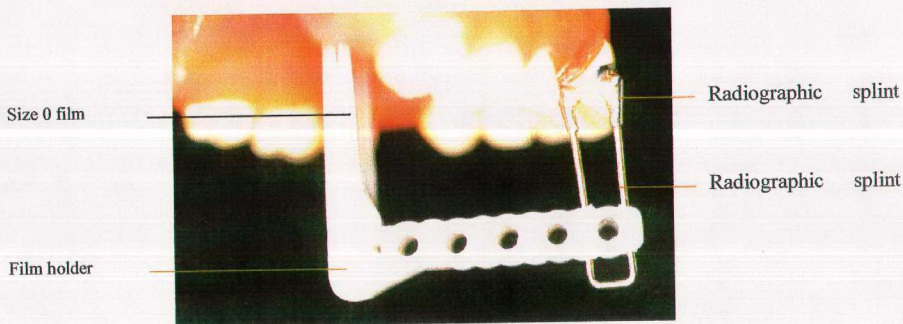
The radiographic splint is assembled and fitted to the canine, occlusal view.



- b -

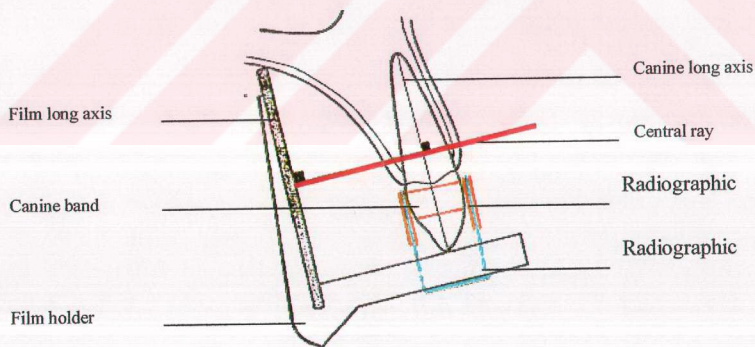
Film placement and the relationship between the central ray, the canine, and the film from occlusal aspect.

Fig.4-7: The radiographic splint, occlusal view.



- a -

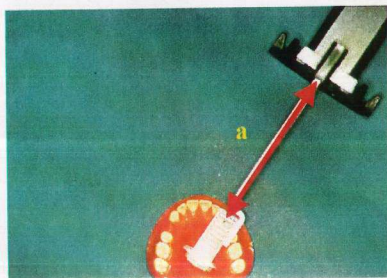
The radiographic splint is assembled and fitted to the canine, lateral view.



- b -

Schematic illustration which shows the central ray projection and the relationship between the

Fig.4-8: The radiographic splint, lateral view.



- a -

The distance between the cone and the tooth (a) is kept constant during the pre-treatment and the post-treatment exposures.

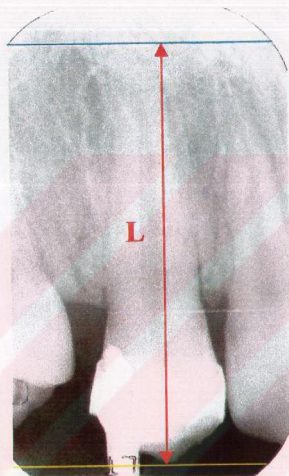


- b -

Central ray point of entry

Fig.4-9: The radiographic splint attached to the x-ray cone.

Root apex level

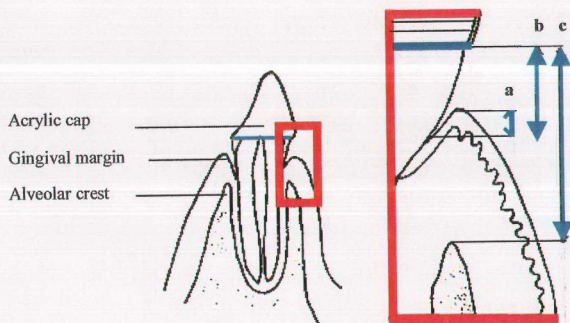


Crown tip level

$$\text{Root resorption} = L (\text{pre-treatment}) - L (\text{post-treatment}),$$

Where L is the total canine length.

Fig.4-10: Root resorption measurement.



a: Probing Pocket Depth. **b:** Probing Attachment Level. **c:** Crestal Bone Height.

Fig.4.11: Parameters used to assess the periodontal health.



- a -



- b -

a: Labial reference points. **b:** Palatal reference points.

Fig.4-12: Acrylic caps.

Name:.....

Date:.....

Please fill out this form 4 hours after morning activation of the screw on the indicated dates.

Please make a small vertical line on each of the horizontal lines below so as to indicate how much discomfort you are experiencing now in the following areas:

Very comfortable

Mild discomfort

Very uncomfortable

(1) At rest:

☺ Rt _____ ☹

☺ Lt _____ ☹

(2) Biting on right canine:

☺ _____ ☹

(3) Biting on left canine:

☺ _____ ☹

(4) Fitting your front teeth together:

☺ Rt _____ ☹

☺ Lt _____ ☹

(5) Fitting your back teeth together:

☺ Rt _____ ☹

☺ Lt _____ ☹

(6) Speech:

☺ _____ ☹

(7) Appearance of teeth:

☺ _____ ☹

Fig.4-13: Visual Analogue Scale forms.

5. Appliance Design and Construction:

5.1. Appliance components:

The distraction appliance was constructed by utilizing the following components:

5.1.1. Retentive components:

Bilateral upper canine and upper first molar bands were soldered to the distraction appliance to attach it to the supporting teeth for retaining it in place during RCR procedure. At the time of insertion, the bands were cemented to the corresponding teeth by light-cured glass ionomer cement (figure 5-1).

5.1.2. Active components:

Prefabricated rapid expander® (from Leone, Firenze- Italy) was modified to decrease its size, for accurate positioning, by eliminating one of the guided pins leaving only one guided pin and the screw (figure 5-2). The body, the screw, and the guided pin are made of stainless steel with no rough areas or intersections for patient comfort. The selected rapid expander arms are made of 1.5 mm stainless steel wire to withstand the activation stresses during distraction. The selected rapid expander maximum expansion limit was 13 mm with a maximum limit of 60 activation turns. Each activation turn, 90°, against the arrow direction, yields an approximation of the two halves of the body by 0.2 mm.

5.1.3. Passive components:

A passive 1.2 mm stainless steel transpalatal arch was soldered to the molar bands for biomechanical considerations (figure 5-3 I). See sections 5.2.d and 5.3.b for details.

5.2. Biomechanical considerations:

Cognitive application of biomechanical concepts in the distraction appliance

design is based on the followings:

5.2.1. Treatment objective:

The treatment objective is to rapidly translate the maxillary canine to the extraction space of the first premolar and to maintain its first order position, i.e. rotation and labio-lingual position.

5.2.2. Required center of rotation:

To achieve translation, the center of rotation was planned to be at infinity. This can be achieved by passing the force through the center of resistance[25], see section 5.2.3.(4)-I for details.

5.2.3. Required force system:

The following criteria characterize the distraction appliance force system which was applied during RCR procedure:

(1)Force magnitude:

After subtotal osteotomy, sufficient orthodontic force magnitudes are needed for the severance of the remaining osseous junction to initiate rapid tooth movement. An orthodontic force of approximately 75 to 200 g is necessary to initiate movement of the osteotomized segment[20]. The second phase of actual segment displacement can be over several days with orthodontic forces under 100 g. Both the initiation and the maintenance of movement are within the scope of contemporary orthodontics. These values are similar to the force values reported during limb distraction using medullary fixation[130,131].

(2)Force direction:

The force should be parallel to the occlusal plane when viewed from the sagittal plane (figure 5-3 F). This can be checked by holding a ruler parallel to the occlusal plane

and then comparing its direction to the screw direction from the midsagittal aspect..

In addition, force direction should be parallel to the line connecting the canine tip with the central fossae of the posterior teeth when viewed from the occlusal plane (figure 5-3 G). This is checked by taking a photostatic copy of the cast (with the screw) and then by drawing a line that represent the direction of the screw axis, and comparing it to the direction of the line connecting the canine tip with the central fossae of the posterior teeth. If the canine is in an off-set or in an in-set position, the force direction should be modified in a way that will bring the canine to the desired first order position by the end of retraction.

(3)Force sense:

The force sense should be directed distally. This can be achieved by opening the rapid expander screw to the required dimension before soldering its arms to the molar and canine bands so that the appliance will be activated by closing the rapid expander, resulting in a distal force on the canine and a medial reactionary force on the first molar and the second premolar.

(4)Point of force application:

I- Corono-apical position: The point of force application should pass through the canine center of resistance when viewed from the sagittal plane to achieve translation. The proposed position of the center of resistance lies at a distance equal to 35% ,of the supported root length, from the tip of the crestal bone[137,138]. Utilizing the paralleling technique, a standard periapical radiograph was obtained, from which the supported root length was measured and the proposed center of resistance was determined (figure 5-6).

Then the distance between the canine tip to this center of resistance was measured. This distance will determine the corono-apical position of the screw, which represents the corono-apical point of force application (figure 5-3 E).

II- Labio-palatal position:

The distraction appliance is to be positioned palatally, therefor, the point of force application lies palatal to both the canine and the molar centers of resistance, when viewed from the horizontal occlusal plane. This will result in unfavorable moments which will tend to rotate the canine disto-labially and the molar mesio-buccally. Therefor, these moments were equilibrated utilizing a transpalatal arch, see section 5.2.d.

5.2.4. Equilibrium state of the force system:

I- First order force system:

- **First order force system without contralateral stabilization (figure 5-5 A):**

1. Canines:

The canines are subject to the following forces and moments:

- Retraction force.
- Mild labial displacement force.
- Mesial in-rotation.

2. First molars:

The first molars are subject to the following forces and moments:

- Mesialization force.
- Mild palatal displacement.
- Distal in-rotation.

- **First order force system with contra lateral stabilization (figure 5-5 B):**

If we assume that the force magnitudes on both sides are equal, then by using a rigid transpalatal arch, the bilateral moments acting on the canines and the molars will cancel each other. In addition, the effect of the bilateral mild palatal forces on the first molars and the bilateral mild labial forces on the canines will also cancel each other. So the final force system will be a distalization force on the canines and a mesialization force on the first molars, which will also affect the second premolars .

II- Second order force system:

Since the line of force action passes in a level close to the centers of resistance of the involved teeth, as viewed from sagittal aspect, we don't expect to have any tipping, intrusion or extrusion forces in the second order force system. So the final force system will again be a distalization force on the canines and a mesialization force on the first molars and second premolars .

III- Third order force system:

Since the Bilateral palatal forces on the first molars and the bilateral labial forces on the canines cancel each other, and since there is no intrusion or extrusion forces, there will be no active third order force system.

5.2.e Appliance activation (figure 5-4):

The distraction appliance was activated 3 days after surgery. The patients were instructed to close the screws 0.8 mm a day by turning them 90° (0.2 mm) every 6 hours .

5.3 Appliance fabrication (figure 5-3):

5.3.a Clinical procedures:

- Placement of elastic separators for one week.

- Placement of canine and first molar bands.
- Upper arch impression with the bands.
- Placement of metallic separators.

5.3.b Laboratory procedures:

- Pouring the impression with dental plaster.
- Determining the corono-apical position of the point of force application on the cast using a vernier.
- Positioning of the modified jackscrews and adapting their arms to the palatal surfaces of the bands.
- Stabilizing the jackscrews by wax.
- Bending and positioning of the transpalatal arch.
- Covering the screws and the transpalatal arch with a wet tissue, to avoid direct contact with plaster, and then with a plaster layer to avoid overheating them.
- Soldering the jackscrews arms and the transpalatal arch to the bands.
- Finishing and polishing.

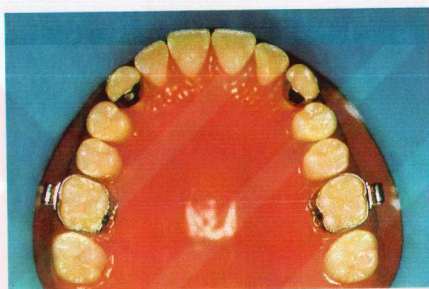
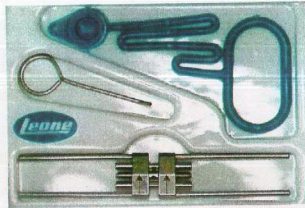
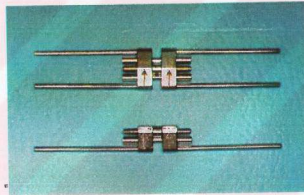


Fig.5-1: Appliance design, retentive components.



- a -

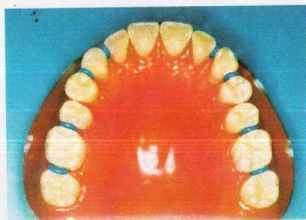
Rapid Expander® (Leone, Firenze – Italy).



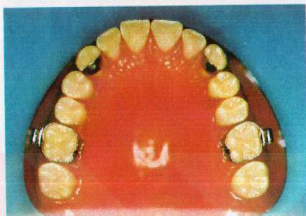
- b -

The modified jackscrew (below) with one guided pin and the screw.

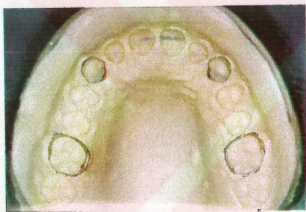
Fig.5.2: Appliance design, Active components.



A: Separation with elastomeric rings.



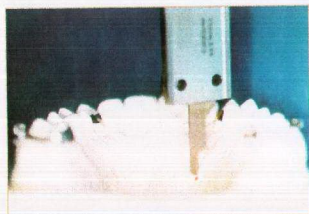
B: Fitting the canine and first molar bands.



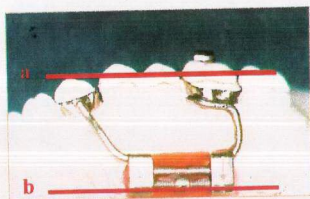
C: Taking the alginate impression with the bands in.



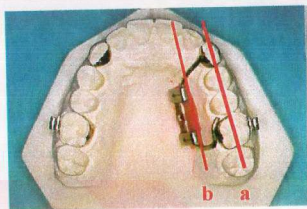
D: Pouring the impression with plaster to have the working model.



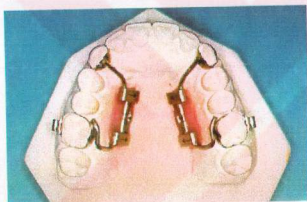
E: Marking the level of the canine center of resistance on the cast.
N.B. Determination of the distance between the canine cusp tip and the center of resistance is done using the standard periapical radiograph as illustrated in figure .



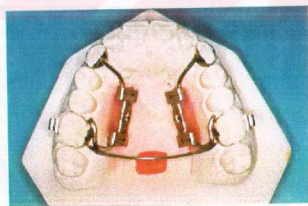
F: Screw direction, lateral view: the screw is positioned at the level of the canine center of resistance, (line b), and parallel to the occlusal plane (line a).



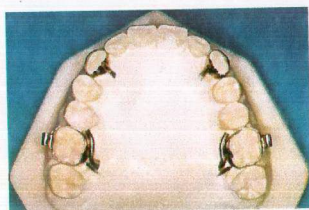
G: Screw direction, occlusal view: the screw is positioned parallel to the line connecting the canine tip with the central fossae of the posterior teeth, (line a) .



H: The other screw is positioned following the same procedures.



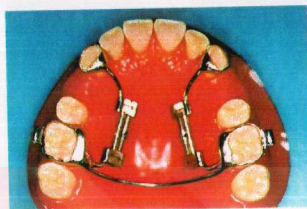
I: The transpalatal arch is adapted in position.



J: Covering the screw and the transpalatal arch with a wet tissue and then with a plaster layer.

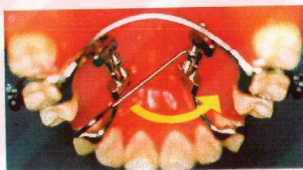


K: Soldering the screws arms to the canine and first molar bands.



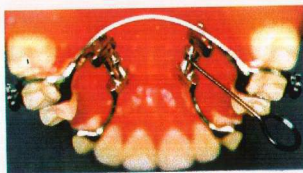
L: Finished appliance.

Fig.5-3: Distraction appliance fabrication, continued.



- a -

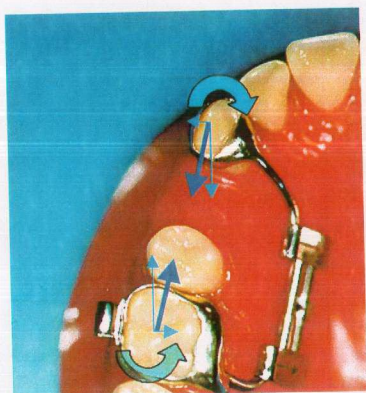
Insertion of the activation key and turning it against the arrow direction.



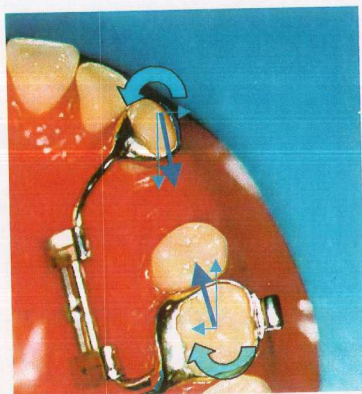
- b -

The screw is stopped by the guided pin when it's turned 90°.

Fig.5-4: Appliance activation.

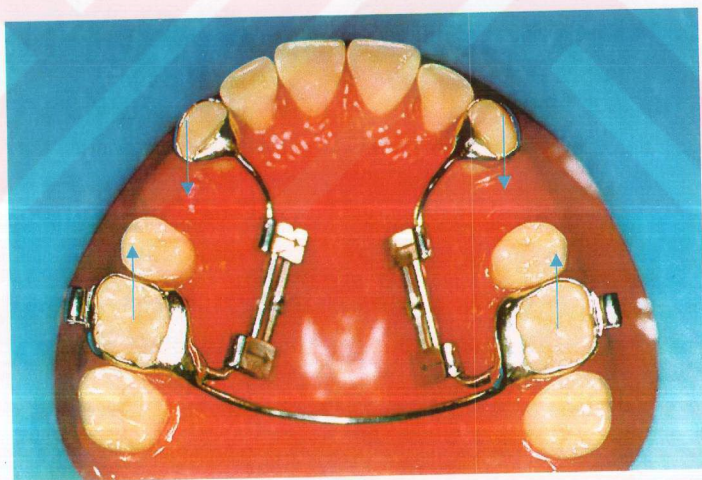


RIGHT SIDE



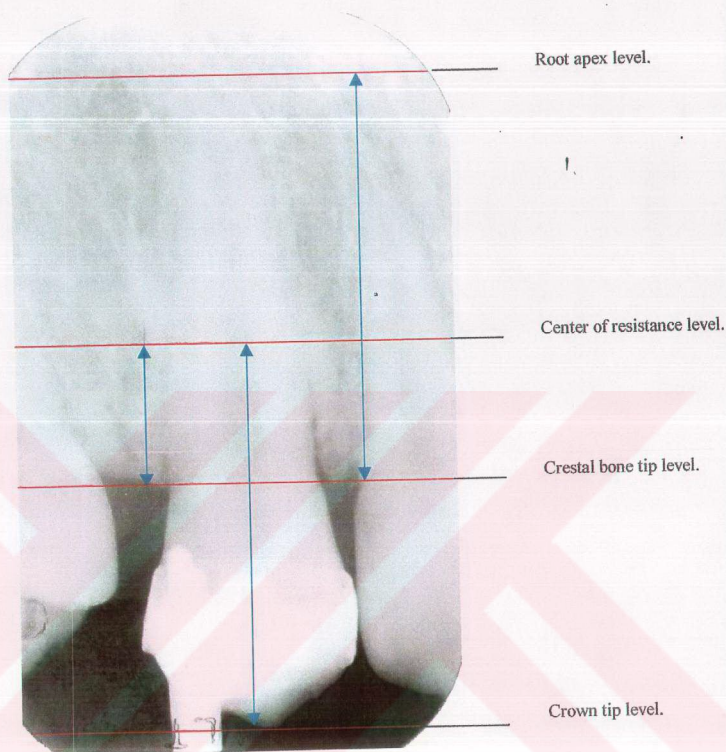
LEFT SIDE

A: The first order force system without contralateral stabilization.



B: The first order force system with contralateral stabilization.

Fig.5-5: Distraction appliance biomechanical analysis



A: Supported root length: the distance between the tip of the interdental crestal bone to the root apex.

B: Radiographic determination of the center of resistance: the proposed level of the center of resistance lies at a distance that is 35% of the supported root length from the tip of the interdental crestal bone.

C: Clinical determination of the center of resistance: the vertical distance between the canine crown tip to the radiographically determined center of resistance.

Example: If the supported root length = 20 mm, then the center of resistance will be at a distance that is 7 mm from the tip of the interdental crestal bone.

Fig.5-6: Determining the center of resistance.

6. Surgery Design:

6.1. Anesthesia:

These surgical procedures were performed under local anesthesia which included: infiltration anesthesia, incisal canal block anesthesia, and inferior orbital block anesthesia. The anesthetic solution (Ultracain®) contained articain HCl (40mg/ml) and epinephrine HCl (0.012mg/ml). The patients were checked for allergy to the anesthetic solution before surgery.

6.2. Flap design (figure 6-1):

- *Buccal vertical incisions*, distal to the most posterior tooth included in the corticotomy procedure, i.e. distal to the second premolar, were extended from the gingival margin towards a level that's 5 mm apical to the apices of the teeth. These buccal vertical incisions on both sides were connected by *intracrevicular incisions* across the incisors.
- *Palatal intracrevicular incisions* were extend from the right first molar to left first molar across the incisors.
- *Mucoperiosteal flaps* were then reflected beyond the level of the apices of the teeth on both aspects. The remaining interdental tissue was preserved.

6.3. Osteotomy and corticotomy designs:

The teeth which were planned for extraction were removed one month earlier and orthodontic separators were placed to open a 1mm space between the canine and the lateral incisor to facilitate the corticotomy of the interdental bone between them.

6.3.1. Alveolar bone distraction side (figure 6-3 and 6-4):

At the alveolar bone distraction side, the following procedures were performed:

- 1- A narrow bone segment (about 4 mm thick) was osteotomized distal to the canine as follows:

Two vertical lines were marked, on both labial and palatal aspects, according to the surgical splint (figure 6-2), by drilling few holes using a round bur #4 to indicate their orientation. One line was 1 mm distal to the canine and the other was 2 mm medial to the second premolar. The holes were then connected by a fissure bur # 556. Then the labial and palatal lines were connected by an oscillating saw. To remove the osteotomized segment, a horizontal osteotomy, 5 mm above the level of the canine apex, was performed using a fine chisel to connect the two lines.

- 2- Vertical buccal and palatal lines were marked and cut through the cortical layer between the lateral incisor and the canine with a fissure bur #556 mounted in a high speed handpiece, starting 1.5 mm above the interdental crest. The tip of the interdental crest between the lateral incisor and the canine was left intact to avoid vertical bone loss or induction of a periodontal defect. This bone will be weakened and severed by the applied orthodontic forces. The apical segment (5mm) of this line was cut through spongiosa too.

- 3- A labial horizontal line was marked, 5 mm above the canine apex, and cut through to the palatal aspect using a fissure bur # 556.

6.3.2. Periodontal membrane distraction side (figure 6-5 and 6-6):

At the periodontal membrane distraction side, a narrow bone segment was also osteotomized as described above. Then from the upper medial corner of the osteotomy site, an oblique scoring was performed towards the canine apex. In addition, two vertical

scoring procedures to the remaining interseptal bone distal to the canine were performed towards the canine root: one on the buccal and the other on the palatal aspect.

The surgical sites were vigorously irrigated with saline prior to flap repositioning and suturing was performed using interrupted interdental sutures.

6.4. Medicaments:

The following medicaments were prescribed:

1- Augmentin® (Amoxicillin trihydrate potassium clavulanate).

2- Apranax® (Naproxen sodium).

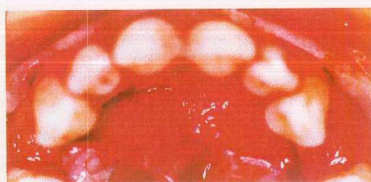
3- Tilcol® (Tenoxicam).

4- Hexoral® (Hexetidine).

Orthodontic appliances were inserted immediately after surgery, but activation started 3 days later.



A: Labial flap.



B: Palatal flap.

Fig.6.1: Flap reflection.



Facial aspect



Palatal aspect

PDL distraction side splint.



Facial aspect



Palatal aspect

PDL distraction side splint.

Fig.6.2: Surgical splints.

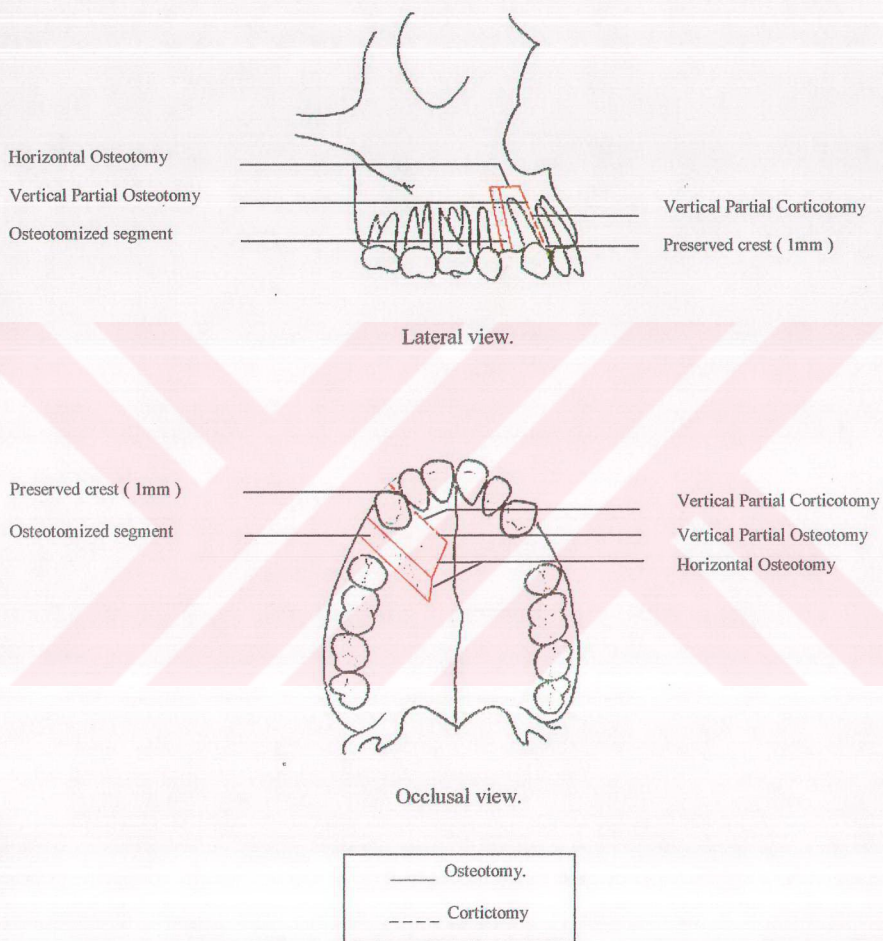
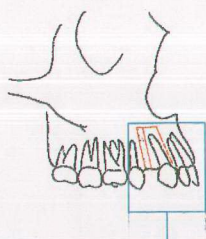


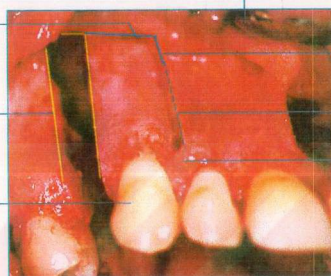
Fig.6.3: Surgery design: Alveolar bone distraction side.



Horizontal osteotomy

Osteotomized segment

Right canine

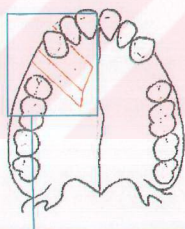


Vertical partial osteotomy

Vertical partial corticotomy

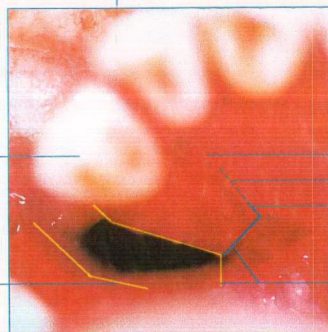
Preserved alveolar crest

Lat



Right canine

Osteotomized segment



Preserved alveolar crest

Vertical partial corticotomy

Vertical partial osteotomy

* Horizontal osteotomy

88

Occlusal view.

FIG 6-4 Alveolar bone distraction side surgery

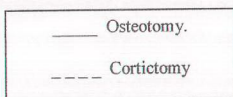
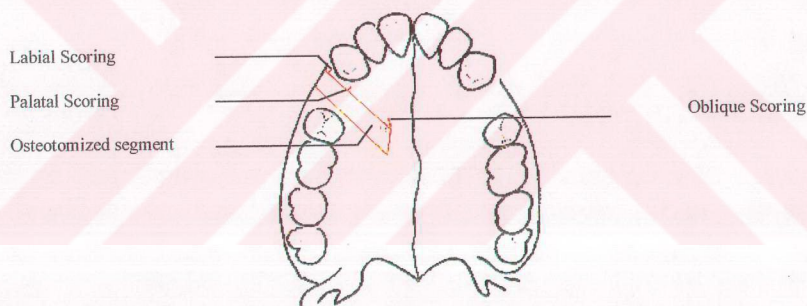
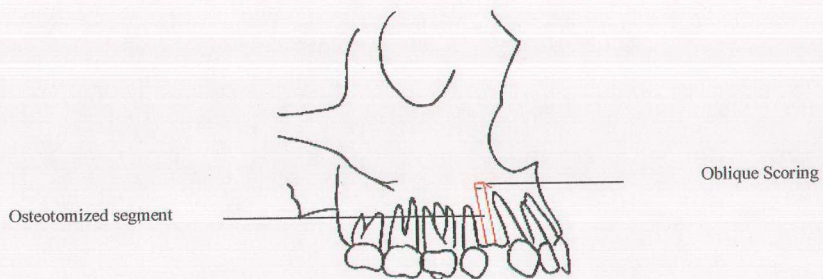


Fig.6.5: Surgery design: PDL distraction side.

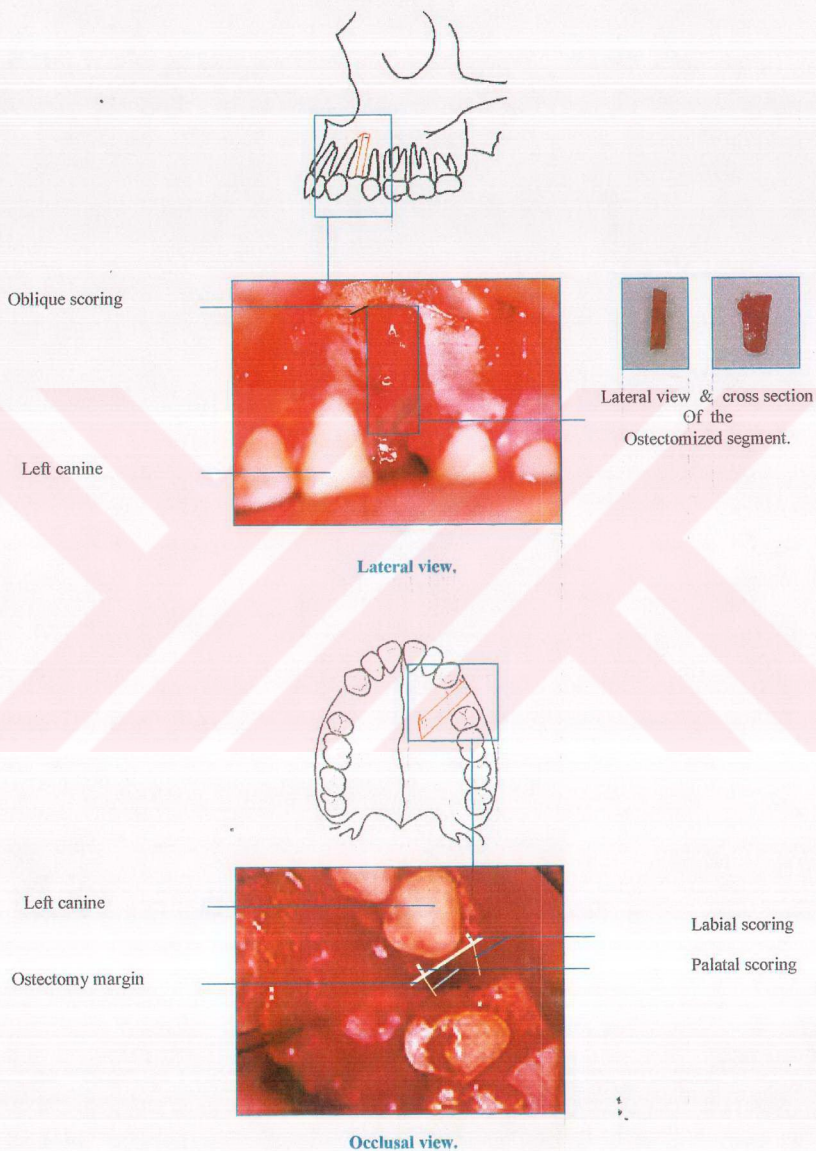


Fig.6-6: PDL distraction side surgery.

7. Results:

Rapid tooth movement was effected by either alveolar bone distraction or periodontal membrane distraction without detrimental effects to the surrounding physiologic environment. In both patients, the canines were rapidly distalized to Class I relationship on both sides (figures 7-1 and 7-2). Detailed description of the findings is described below.

7.1. Assessment of and comparison between two RCR techniques: regarding the nature of tooth movement (tipping versus translation), the rate of retraction, and anchorage loss:

- **Nature of retraction (tipping *versus* bodily):**

1- Alveolar bone distraction side:

Utilizing the following equation to calculate the retraction distance:

$$\text{Retraction distance (mm)} = C (\text{pre-treatment}) - C (\text{post-treatment}),$$

(where C is the horizontal distance between the constructed true vertical plane and the canine marker), the canines were retracted an average of 5mm (6mm in patient no.1 and 4mm in patient no.2) to reach class I relationship (figures 7-3 and 7-4).

Utilizing the following equation to calculate tipping

$$\text{Tipping (}^\circ\text{)} = T (\text{post-treatment}) - T (\text{pre-treatment}),$$

(where T is the anterior angle between the constructed true horizontal and the canine marker extension), the canines were slightly tipped distally, an average of 1.5°.

In patient no.1: the tipping amount was -1°, which indicated not only translation, but also 1° distal root torque (figure 7-3).

In patient no.2: the tipping amount was +4°(around a center of rotation that was 23mm above and 24mm anterior to the canine apex), which indicated a combination of translation and distal crown tipping (figure 7-4).

2- Periodontal membrane distraction side:

In the periodontal distraction side: the canines were retracted an average of 4.25mm (5.5mm in patient no.1 and 3mm in patient no.2), with average tipping amount equal to +5.25° (figures 7-5 and 7-6).

In patient no.1: the tipping amount was +4.5° (around a center of rotation that was 38mm above the canine apex), which indicated a combination of translation and distal crown tipping (figure 7-5).

In patient no.2: the tipping amount was +6° (around a center of rotation that was 10mm below the canine apex), which indicated uncontrolled tipping (figure 7-6).

3- Comparison:

Rapid canine retraction (RCR) by alveolar bone distraction resulted in less tipping (average +1,5° after 5 mm distalization) than RCR by periodontal membrane distraction (average +5.25° after 4.25mm distalization) (table 7-1).

• Rate of retraction:

1- Alveolar bone distraction side:

Canine retraction started 6 days after the beginning of distraction appliance activation, in both patients.

Utilizing the following equation to calculate retraction rate:

$$\text{Retraction rate (mm/day)} = \text{Retraction distance (mm)} / \text{Retraction time (day)},$$

we found that the average retraction rate was 1mm/day.

In patient no.1: it took 5 days, after the commencement of movement, to retract the canine 6mm, so the retraction rate was 1.2mm/day.

In patient no.2: it took 5 days, after the commencement of movement, to retract the canine 4mm, so the retraction rate was 0.8mm/day. In this patient, the right lateral and central incisors were retracted along with the canine, perhaps due to interseptal fibers stretching. This might have caused slower retraction rate than that in patient no.1.

2- Periodontal membrane distraction side:

Canine retraction started 8 days after the beginning of distraction appliance activation. The rate of retraction was 0.6mm/day for both patients.

In patient no.1: it took 9 days, after the commencement of movement, to retract the canine 5.5mm, so the retraction rate was 0.6mm/day.

In patient no.2: it took 5 days, after the commencement of movement, to retract the canine 3mm, so the retraction rate was 0.6mm/day.

3- Comparison:

RCR by alveolar bone distraction started earlier (6 days) after the beginning of activation and continued with faster retraction rate (1.0mm/day) than RCR by periodontal membrane distraction which started (8 days) after the beginning of activation at a retraction rate of (0.6mm/day) (table 7-2).

• Anchorage loss:

1- Alveolar bone distraction side:

Utilizing the following equation to calculate the anchorage loss:

$$\text{Anchorage Loss (mm)} = M (\text{post-treatment}) - M (\text{pre-treatment}),$$

(where: M is the horizontal measurement between the constructed true vertical plane and the first molar marker), the average anchorage loss was 0.25mm.

In patient no.1: there was no anchorage loss (figure 7-7), while in patient no.2: 0.5mm anchorage loss was measured (figure 7-8).

2- Periodontal membrane distraction side:

In the periodontal membrane distraction side, there was an average of 0.25mm anchorage loss.

In patient no.1: no anchorage loss was noticed (figure 7-7), while in patient no.2: 0.5mm anchorage loss was noticed (figure 7-8).

3- Comparison:

There was no difference between RCR by alveolar bone distraction and RCR by periodontal membrane distraction regarding the anchorage status of the posterior segment. Both modalities resulted in minimal anchorage loss (0.25mm) (table 7-3).

Patient no.2 showed 0.5mm anchorage loss which could be due to en-mass retraction of the six anterior teeth.

7.2. Assessment of new alveolar bone formation and remodeling after RCR:

1- Alveolar bone distraction side:

After distraction, a wide radiolucent zone was noticed distal to the canine root. It became narrower in 3 weeks (figure 7-9), which indicated that striated bone formation was progressing from the proximal sides of the radiolucent zone towards its center.

2- Periodontal membrane distraction side:

The radiographic changes of the periodontal membrane medial to the retracted canines started by widening of the periodontal membrane immediately after retraction. Evidence of striated bone formation in the distraction space was noticed 3 weeks after

distraction (figure 7-9). Eventually, recovery of the periodontal membrane was noticed 6 weeks after distraction.

3- Comparison:

Both modalities of RCR resulted in optimal bone formation.

7.3. Assessment of root resorption during and after RCR:

1- Alveolar bone distraction side:

Comparing the pre-treatment and post-treatment (2 weeks after retraction) standard periapical radiographs showed no decrease in the overall length of the retracted canines, which means that there was no measurable apical root resorption (figures 7-11 A,B). In addition, the lateral surfaces of the retracted canines were smooth which indicated no lateral root resorption.

2- Periodontal membrane distraction side:

The overall length of the retracted canines was similar on the pre-treatment and the post-treatment standard periapical radiographs, which indicated the absence of root resorption (figures 7-11 A,B). In addition, the lateral surfaces of the retracted canines were smooth which indicated no lateral root resorption.

3- Comparison:

Both treatment modalities of RCR showed favorable results regarding root resorption. It was totally absent (table 7-4).

7.4. Assessment of dental pulp vitality after RCR:

1- Alveolar bone distraction side:

Post-treatment electronic pulp testing yielded a negative response which

indicated decreased sensitivity. Laser Doppler flowmetry detected positive pulsatile blood flow to the dental pulp of the retracted canines which indicated that they are vital teeth.

2- Periodontal membrane distraction side:

Post-treatment electronic pulp testing yielded a positive response at higher thresholds which indicated decreased sensitivity. Laser Doppler flowmetry detected positive pulsatile blood flow to the dental pulp of the retracted canines, which indicated that they are vital teeth.

3- Comparison:

In both RCR modalities, retracted canines showed decreased sensitivity. Nevertheless, their vitality was maintained (table 7-5).

7.5. Assessment of periodontal health after RCR:

Regarding the periodontal health assessment, the results obtained in this study should be interpreted with care, as initial recordings were taken before surgery and before the placement of bands while the final recordings were taken after a surgical intervention which was followed by banding the teeth. The data on the pocket depth, attachment level, and crestal bone height changes (tables 7-6 and 7-7) demonstrate that the surgical procedure and both RCR modalities procedures were not excessively damaging to the periodontal tissues. Gingival recession was minimal and the interdental papillae were preserved, insuring a good post-treatment esthetic results (figures 7-1 and 7-2).

7.6. Assessment of prevalence, intensity, and duration of pain or discomfort perception associated with rapid canine retraction treatment (figure 7-12):

1- Alveolar bone distraction side:

Patients reported moderate discomfort at the beginning of distraction. Then the level dropped to mild discomfort in few days.

2- Periodontal membrane distraction side:

In the periodontal membrane distraction side, when biting on the canine patients reported severe discomfort immediately after appliance activation at the beginning of distraction (figure 7-12 B). When tooth movement started, the level of discomfort dropped to moderate.

3- Comparison:

In all discomfort categories which were assessed to compare between the two RCR modalities, the patients generally indicated less discomfort at the alveolar bone distraction side than at the periodontal membrane distraction side at initial stages after the commencement of distraction. In addition, at the beginning of distraction, patients reported severe discomfort immediately after appliance activation at the periodontal membrane distraction side.

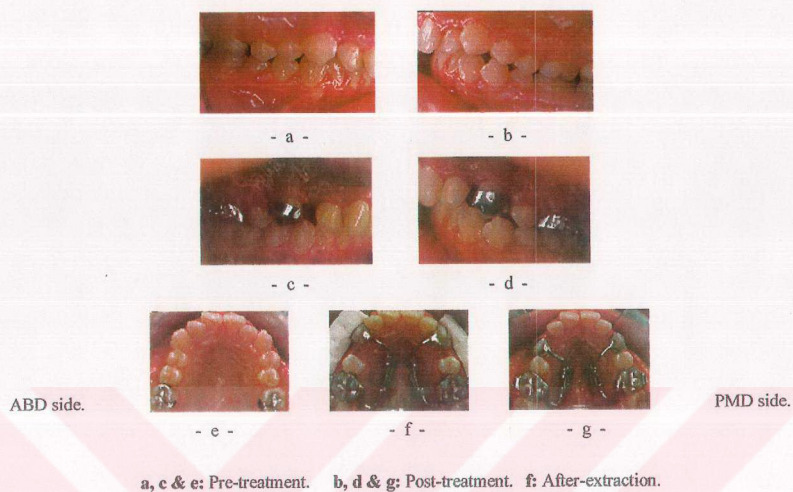


Fig.7-1: Pre-treatment and post-treatment records of patient No.1.

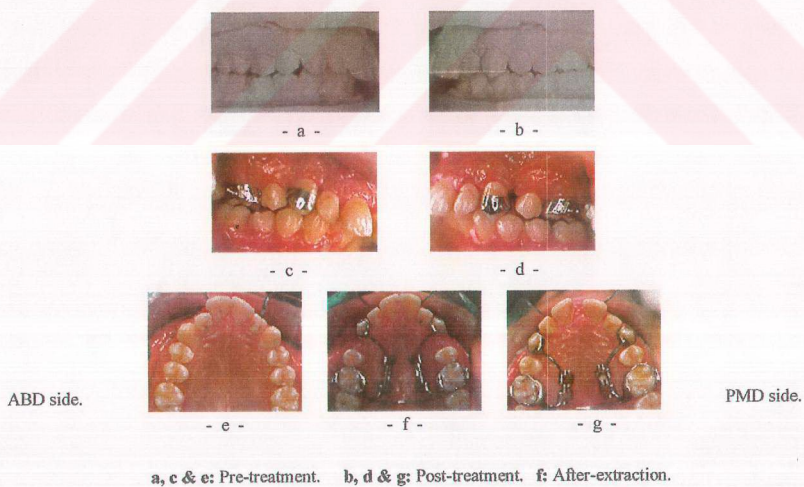
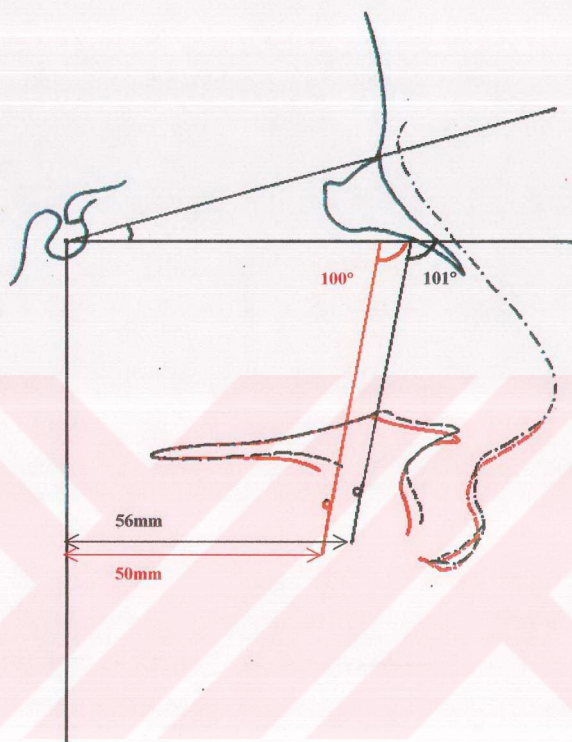


Fig.7-2: Pre-treatment and post-treatment records of patient No.2.

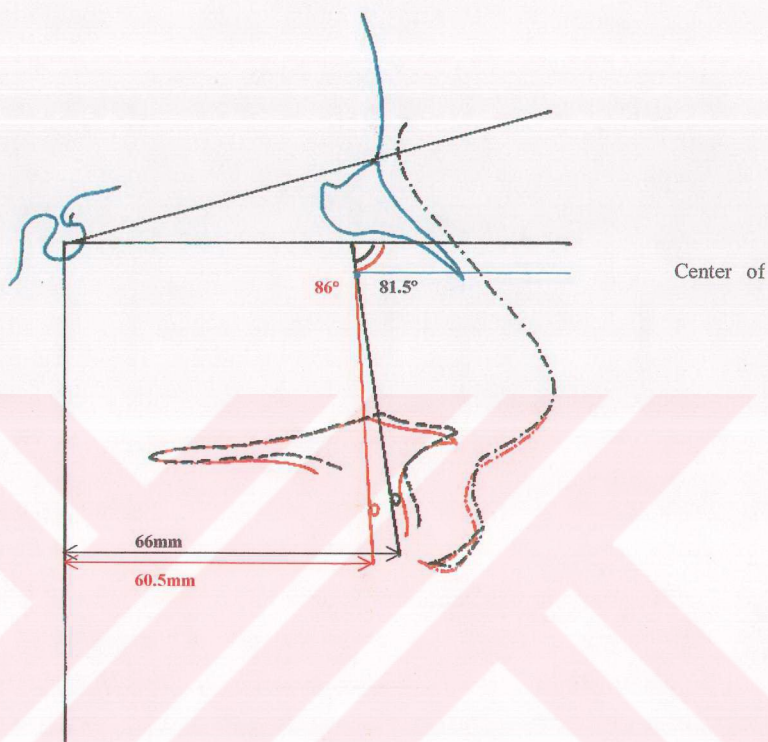


Patient No.1: Alveolar bone distraction side.

$$\text{Tipping} = 100 - 101 = -1^\circ.$$

$$\text{Retraction distance} = 56 - 50 = 6\text{mm}.$$

Fig.7-3: Tipping and retraction distance measurement.

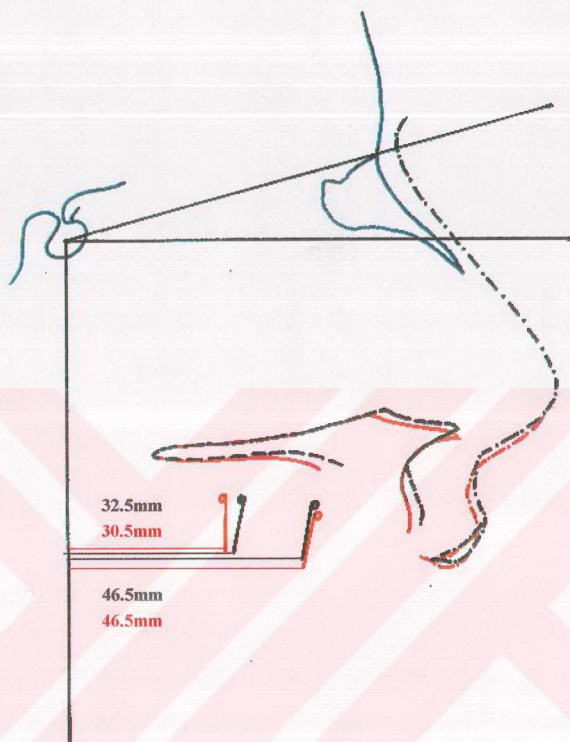


Patient No.1: Periodontal membrane distraction side.

$$\text{Tipping} = 86 - 81.5 = 4.5^\circ.$$

$$\text{Retraction distance} = 66 - 60.5 = 4.5\text{mm}.$$

Fig.7-4: Tipping and retraction distance measurement.



Patient No.1

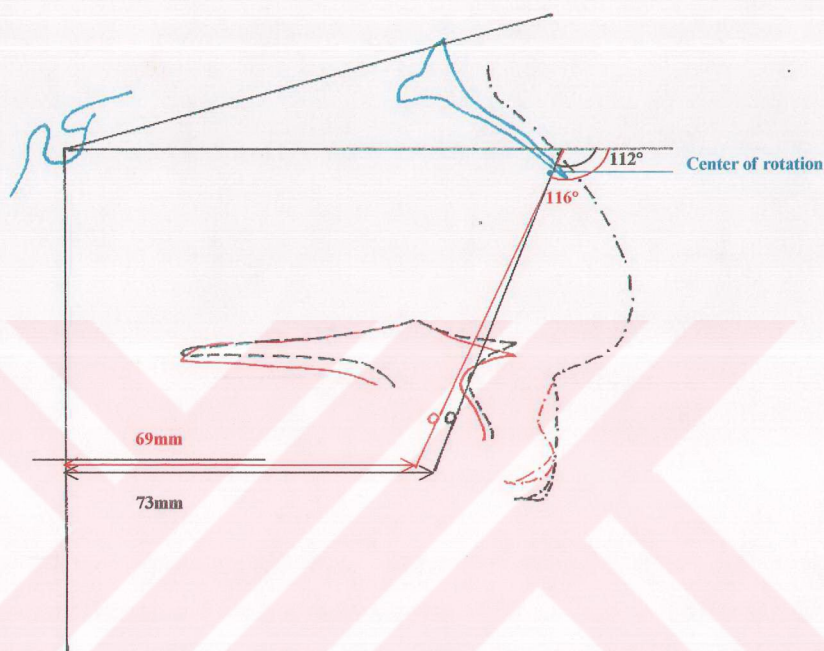
Alveolar bone distraction side.

Anchorage loss = $30.5 - 32.5 = -2\text{mm}$.

Periodontal membrane distraction side.

Anchorage loss = $46.5 - 46.5 = 0\text{mm}$

Fig.7-5: Anchorage loss measurement.

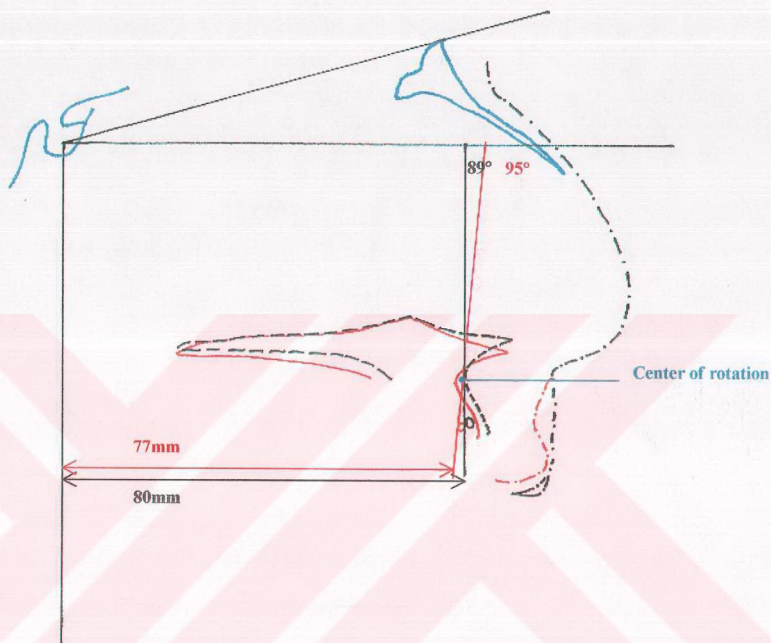


Patient No.2: Alveolar bone distraction side.

Tipping = $116 - 112 = 4^\circ$.

Retraction distance = $73 - 69 = 4\text{mm}$.

Fig.7-6: Tipping and retraction distance measurement.

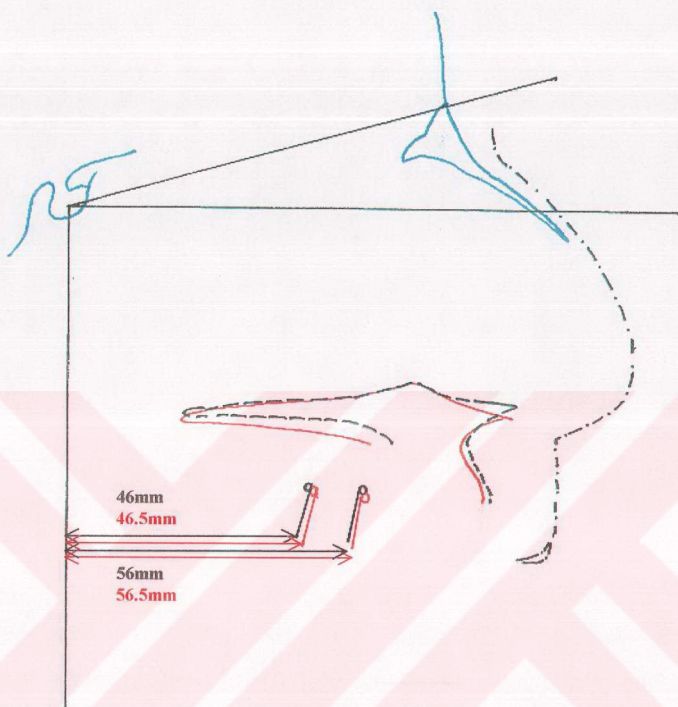


Patient No.2: Periodontal membrane distraction side.

Tipping = $95 - 89 = 6^\circ$.

Retraction distance = $80 - 77 = 3\text{mm}$.

Fig.7-7: Tipping and retraction distance measurement.



Patient No.2

Alveolar bone distraction side.

Anchorage loss = $30.5 - 32.5 = -2\text{mm}$.

Periodontal membrane distraction side.

Anchorage loss = $46.5 - 46.5 = 0\text{mm}$

Fig.7-8: Anchorage loss measurement.

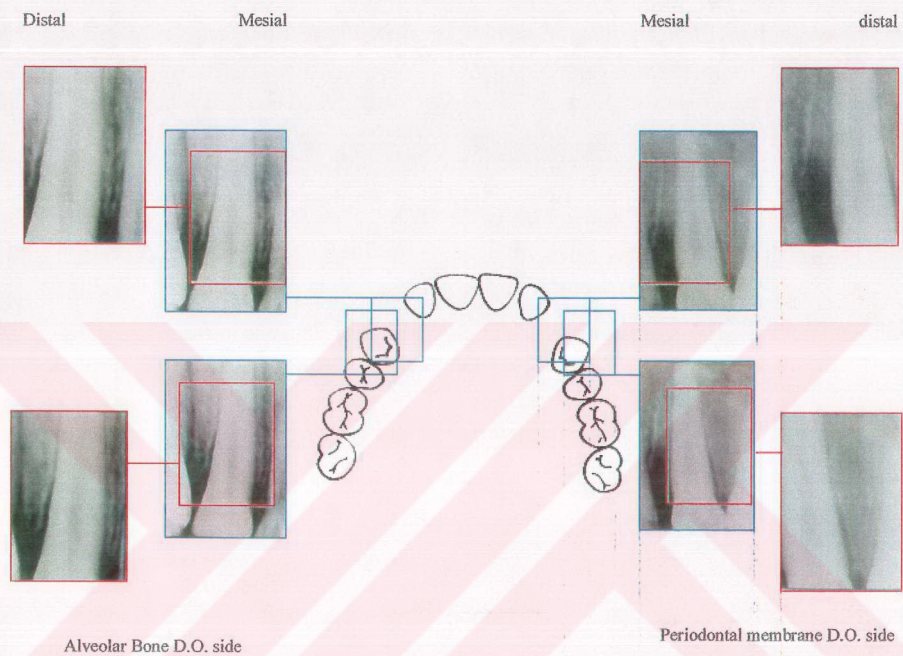


Fig.7-9-A: Radiographic assessment of the retracted canines, 3 weeks after retraction.

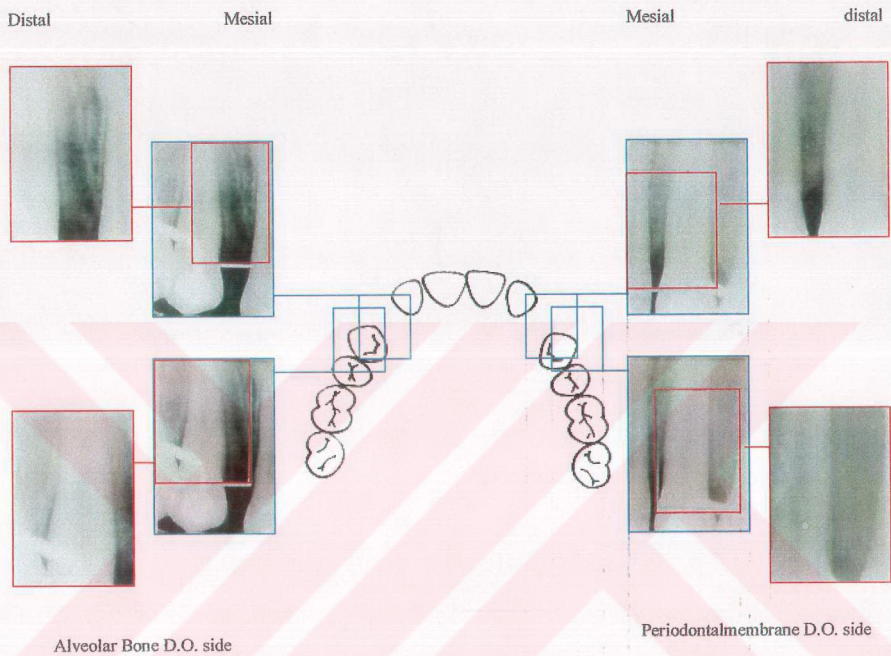
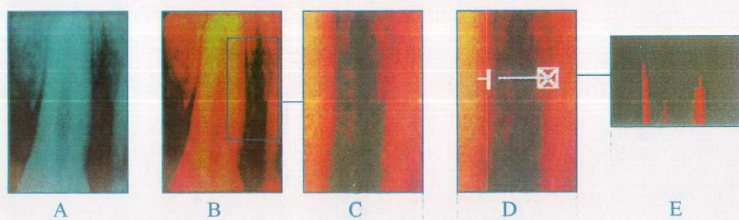
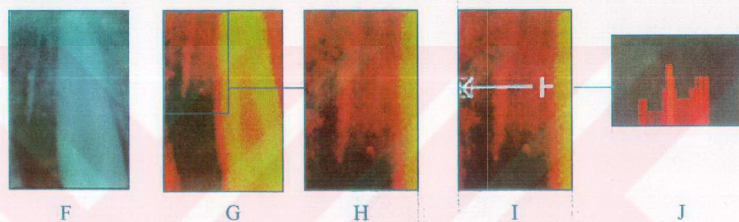


Fig.7-9-B: Radiographic assessment of the retracted canines, 6 weeks after retraction.

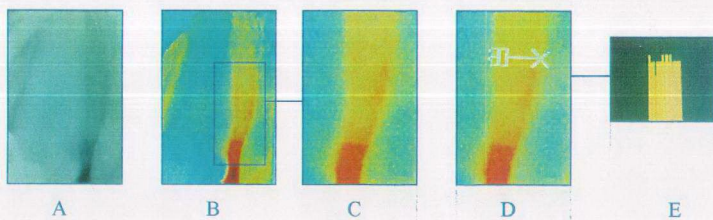


Alveolar Bone Distraction side

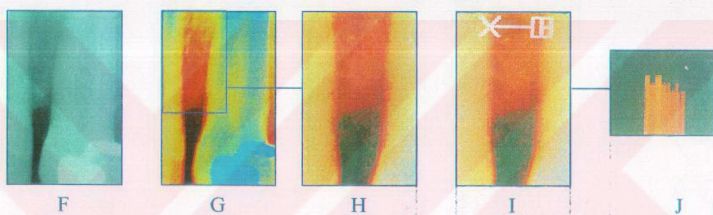


Periodontal Membrane Distraction side

Fig.7-10-A: Densitometric analysis, 3 weeks after distraction.

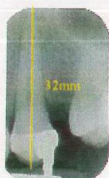


Alveolar Bone Distraction side

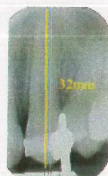


Periodontal Membrane Distraction side

Fig.7-10-B: Densitometric analysis, 3 weeks after distraction.



- A -



- B -

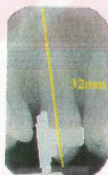
The alveolar bone distraction side:

A: Pre-treatment radiograph: the overall canine length (including the crown and root) is 32 mm.

B: Post-treatment radiograph: the overall canine length (including the crown and root) is 32 mm.

$$\text{Root Resorption} = 32 - 32 = 0 \text{ mm}$$

The distal root surface seems smooth and there is no apparent irregularities.



- C -



- D -

The periodontal membrane distraction side:

C: Pre-treatment radiograph: the overall canine length (including the crown and root) is 32 mm.

D: Post-treatment radiograph: the overall canine length (including the crown and root) is 32 mm.

$$\text{Root Resorption} = 32 - 32 = 0 \text{ mm}$$

The distal root surface seems smooth and there is minimal irregularities.

Fig.7-11: Root resorption calculation.

Patient	Technique Measurement	Alveolar bone D.O.	PDL D.O.
No.1	Pre-treatment Angulation (°)*	101	81.5
	Post-treatment Angulation (°)*	100	86
	Tipping (°)	-1	+4.5
No.2	Pre-treatment Angulation (°)*	112	89
	Post-treatment Angulation (°)*	116	95
	Tipping (°)	+4	+6
Average Tipping (°)		+1.5	+5.25

*The anterior angle that is formed by the intersection of the constructed true horizontal and the inclination axis of the canines, which were represented by radiographic markers.

Table 7-1: Tipping calculations.

Patient	Technique Measurement	Alveolar bone D.O.	PDL D.O.
No.1	Pre-treatment Distance (mm)*	56	66
	Post-treatment Distance (mm)*	50	60.5
	Retraction Distance (mm)	6	5.5
	Retraction Time (Day)	5	9
	Retraction Rate (mm/day)	1.2	0.6
No.2	Pre-treatment Distance (mm)*	73	80
	Post-treatment Distance (mm)*	69	77
	Retraction distance (mm)	4	3
	Retraction Time (Day)	5	5
	Retraction Rate (mm/day)	0.8	0.6
Avg. Retraction Rate(mm/day)		1.0	0.6

*The horizontal distance between the constructed true vertical and the canine marker lower end.

Table 7-2: Retraction rate calculations.

Patient	Technique	Alveolar bone	PDL
	Measurement	D.O.	D.O.
No.1	Pre-treatment Distance (mm)*	30.5	46.5
	Post-treatment Distance (mm)*	30.5	46.5
	Anchorage loss (mm)	0	0
No.2	Pre-treatment Distance (mm)*	46	56
	Post-treatment Distance (mm)*	46.5	56.5
	Anchorage loss (mm)	0.5	0.5
Avg. Anchorage Loss (mm)		0.25	0.25

*The horizontal distance between the constructed true vertical and the first molar marker lower end.

Table7-3: Anchorage loss calculations.

Patient	Technique	Alveolar bone D.O.	PDL D.O.
No.1	Pre-treatment Length (mm)*	29	30
	Post-treatment Length (mm)*	?	?
	Root Resorption (mm)	?	?
No.2	Pre-treatment Length (mm)*	32	32
	Post-treatment Length (mm)*	32	32
	Root Resorption (mm)	0	0

*The overall length of the canine as measured from the standard periapical radiograph.

Table 7-4: Root resorption calculations.

Patient	Technique Measurement	Alveolar bone D.O.	PDL D.O.
No.1	Pre-treatment Response*	+	+
	Post-treatment Response*	-	+
No.2	Pre-treatment Response*	+	+
	Post-treatment Response*	-	+

*Electronic pulp testing.

Table7-5: Pulp vitality test results.

Technique		Alveolar bone D.O.		PDL D.O.	
Time		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Attachment level	Mes-Lab	6	5.5	6	4
	Mid-Lab	3	4.5	4	3.5
	Dist-Lab	3	4	4.5	4
	Mes-Pal	4	5.5	5	3.5
	Mid-Pal	3.5	6	5	3
	Dist-Pal	4	4	4.5	4.5
Pocket depth	Mes-Lab	2	1.5	2	2
	Mid-Lab	1	1.5	1.5	2
	Dist-Lab	1	2	2.5	3
	Mes-Pal	2	2	2	2
	Mid-Pal	1.5	3	2	2
	Dist-Pal	2	3	1.5	3
Bone level*	Mes-Lab	8.5	9.5	8	8
	Mid-Lab	7.5	8	7.5	7
	Dist-Lab	7	7.5	6	7
	Mes-Pal	7	7	7	7
	Mid-Pal	7	8	8	9
	Dist-Pal	7	7	5.5	6

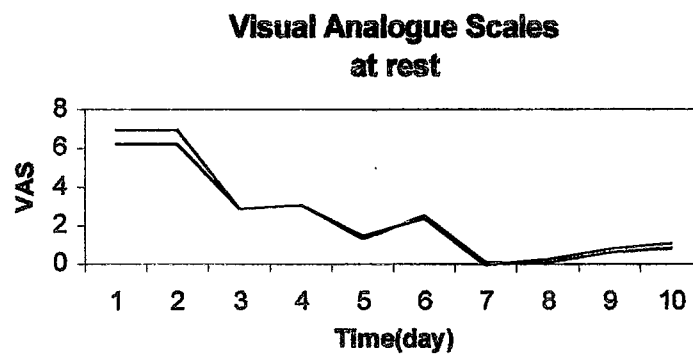
*Sounding.

Table7-6:Assessment of the periodontal health of patient No.1 four weeks after retraction.

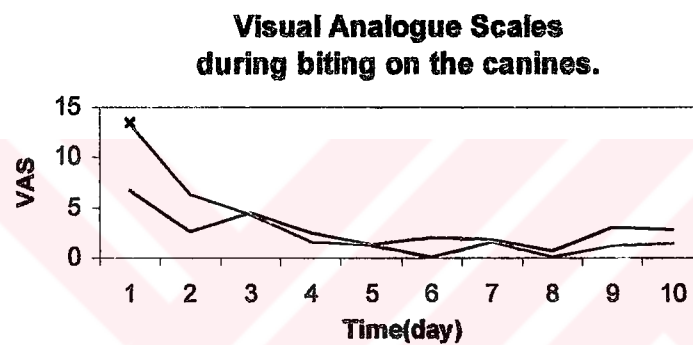
Technique		Alveolar bone D.O.		PDL D.O.	
Time		Pre-treatment	Post-reatment	Pre-treatment	Post-treatment
Attachment level	Mes-Lab	4.5	7	4.5	7
	Mid-Lab	4.5	6	4.5	6
	Dist-Lab	6	7	5.5	7
	Mes-Pal	5	5	5.5	6
	Mid-Pal	5	5	4.5	6
	Dist-Pal	7	7	5.5	6
Pocket depth	Mes-Lab	1.5	1	1.5	1
	Mid-Lab	1	1	1.5	1
	Dist-Lab	2	1	2.5	1.5
	Mes-Pal	2	2	2.5	2
	Mid-Pal	1.5	2	1.5	2
	Dist-Pal	2	2	2	2
Bone level*	Mes-Lab	9	8	8	8
	Mid-Lab	9	8	8	8
	Dist-Lab	9	8	7	8.5
	Mes-Pal	8.5	7.5	7	7
	Mid-Pal	8	8	7	7
	Dist-Pal	8.5	7	6	9

*Sounding.

Table7-7: Assessment of the periodontal health of patient No.2 three weeks after retraction.



- A -



- B -

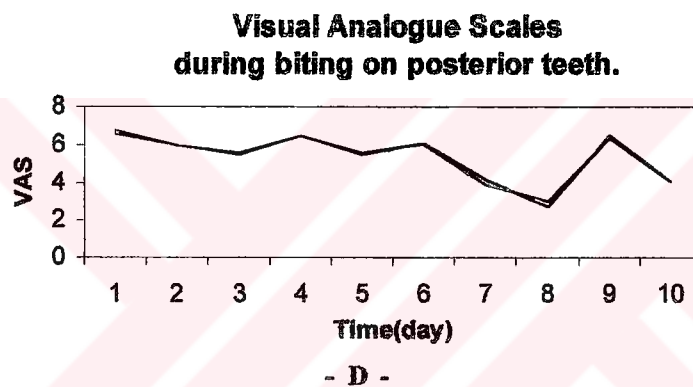
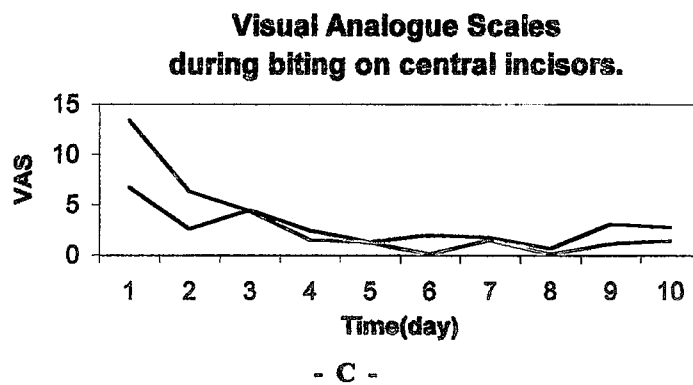
VAS:1-5 (mild discomfort),5-10 (moderate discomfort), and 10-15 (severe discomfort).

Time: starting at day 1 of distraction.

Red plot: is for the periodontal membrane distraction side visual analogue scales.

Blue plot: is for the alveolar bone distraction side visual analogue scales.

Fig.7-12: Visual Analogue Scale vs. Time plots.



VAS: 1-5 (mild discomfort), 5-10 (moderate discomfort), and 10-15 (severe discomfort).

Time: starting at day 1 of distraction.

Red plot: is for the periodontal membrane distraction side visual analogue scales.

Blue plot: is for the alveolar bone distraction side visual analogue scales.

Fig.7-12: Visual Analogue Scale vs. Time plots.

8. Discussion:

In this study, we have demonstrated that it is possible to retract the canines rapidly into extraction spaces after minor surgical intervention by either alveolar bone distraction or periodontal membrane distraction.

Rapid retraction of 4 canines (2 by alveolar bone distraction procedures and 2 by periodontal membrane distraction procedures) in 2 patients (1 female and 1 male) were carried out with custom-made, tooth-borne, intra-oral, unidirectional distraction devices utilizing modified jackscrews, which were inserted immediately after a minor surgical intervention and activated three days later. The distraction devices were activated 0.2 mm four times a day (total activation 0.8 mm/day) until desired canine position was reached. The consolidation period lasted for 8 weeks, during which leveling of anterior segment was achieved.

The rapid tooth movement is different from purely orthodontic movement. Orthodontic tooth movement occurs principally within the dental alveolus, whereas in rapid canine retraction by alveolar bone distraction concomitant orthodontic movement occurs at the osseous interfaces between alveolar bone segments[20], while in rapid canine retraction by periodontal membrane distraction bending of the alveolar bone occurs, whereby the tooth root and the alveolus are displaced together[7].

The concept of achieving rapid tooth movement by weakening the alveolar bone utilizing an osteotomy or a corticotomy is not new. Bichlmayr[5] used that method in an Angle Class II malocclusion with dental protrusion and open bite. He carried out the movement of the teeth after extracting first premolars. A wedge-shaped bone resection on the alveolar process lingual to the anterior teeth was accomplished to facilitate retraction

and alignment. However, the time required to accomplish the desired movement with orthodontic treatment was several months.

Gantes *et al.*[6] described a surgical technique with multiple corticotomies used in conjunction with orthodontic therapy to facilitate orthodontic tooth movement in five adult patients who exhibited different orthodontic problems. The mean treatment time was 14.8 months for the experimental group and 28.3 months for the control group. However, most of the orthodontic movement of the canines was accomplished in seven months.

Liou *et al.* [7] (1998) reported rapid retraction of twenty six canines, utilizing dental distraction of the periodontal ligament after minor surgical scoring of the interseptal bone at the time of the first premolar extraction.. They claimed that most of the canines were moved bodily 6.5 mm, in three weeks. In addition, their study results showed that 73% of the first molars did not move medially and 27% of them moved less than 0.5 mm medially within the retraction period.

In our study, RCR by alveolar bone distraction started earlier (6 days) after the beginning of activation and continued with faster retraction rate (1.0mm/day) than RCR by periodontal membrane distraction which started (8 days) after the beginning of activation at a retraction rate of (0.6mm/day) (table 7-2). In addition, There was no difference between RCR by alveolar bone distraction and RCR by periodontal membrane distraction regarding the anchorage status of the posterior segment. Both modalities resulted in minimal anchorage loss (0.25mm) (table 7-3).

The periodontal strain during RCR by alveolar bone distraction after a subtotal osteotomy is slight[133]. An orthodontic force of approximately 75 to 200 gm is

necessary to initiate movement of the osteotomized segment. The second phase of actual segment displacement can be over several days with orthodontic forces under 100 gm. Both the initiation and the maintenance of movement are within the scope of contemporary orthodontics[20].

On the other hand, during RCR by periodontal membrane distraction, the danger of local osteonecrosis exists because of the employment of unphysiologic forces[133-136] which are indicated by the difficulty to activate the screws and the associated severe discomfort which was reported by patients. If there is delayed movement and an excessive orthodontic force is continued on the assumption that tooth movement can still be effected, the danger of permanent periodontal damage must not be underestimated.

Applying distraction force at the proposed level of the center of resistance of the canine[137,138] lead to a pure translation of the tooth and the surrounding alveolus in the alveolar bone distraction side, whereas in the periodontal membrane distraction side the movement was a combination of tipping and translation, perhaps due to high resistance at the root apex level.

After initial tooth movement by heavy orthodontic force, a lag period of minimal tooth movement persists for approximately 2 to 3 weeks before tooth movement proceeds again[139,140]. In this study, canine retraction was completed in 10 to 14 days, while the molars were still in the lag period, which explains the minimal anchorage loss in the posterior segment. Therefore, in critical anchorage cases where patient cooperation is questionable, RCR can be utilized to retract the canines without forcing the anchorage.

Factors affecting bone formation during and after distraction were discussed in detail in section three. Maintenance of sufficient blood supply is of considerable

importance if successful results are to be anticipated. In the alveolar bone distraction side, maintenance of blood supply is dependent on the surgical technique [35,141]. The extent of the gingival incision and the distance of the horizontal osteotomy from the root apices are decisive factors that influence the blood supply to the segment[20]. The subtotal subapical osteotomy preserves blood supply to the dentoalveolus segment, since the partially osteotomized segment remains attached to the alveolar process via the soft tissue pedicle and incompletely sectioned bone during distraction.

Many authors described the osteogenesis process after experimental distraction procedures utilizing radiographic, histologic, and biochemical methods. Precise mineral content was inspected by measuring the amount of radiation absorption produced by an iodine-125 source in a clinical study, but it involves complex methodology that is only feasible in research[117]. In addition, dual energy photon x-rays (DEPX) technique was utilized in an experimental study, in animals, to measure the bone mineral content during distraction osteogenesis[118].

Bone densitometry is another technique that can be used to inspect bone mineral content. Although some authors reported poor correlation between radiographic density and the *biomechanical integrity* of newly formed bone[119,120], Cobo *et al.* [121] measured the course of bone formation in the midpalatal suture after rapid maxillary expansion by bone densitometry. Statistically significant changes in midpalatal suture density were evident throughout the period studied, since the beginning of expansion till five weeks later. Therefore, it was concluded that bone densitometry can be utilized to follow up the progression of bone formation.

In our study, we utilized the densitometry technique to measure bone density in the retraction space to follow up the progression of bone formation and remodeling after retraction. In the Alveolar Bone distraction side: a wide intermediary radiolucent zone was noticed between the canine and the lateral incisor after distraction. It became narrower in 3 weeks (figures 7 and 8), which indicated that striated bone formation was progressing from the proximal sides of the radiolucent zone towards its center. Complete ossification of this zone was noticed 6 weeks after retraction (figures 7 and 8), which indicated the union of the two alveolar bone fragments.

In the Periodontal Membrane distraction side: the radiographic changes of the periodontal membrane medial to the retracted canines started by widening of the periodontal membrane immediately after retraction. Evidence of striated bone formation in the distraction space was noticed 3 weeks after distraction (figures 9 and 10). Eventually, recovery of the periodontal apparatus with the formation of new lamina dura was noticed 6 weeks after distraction (figures 9 and 10).

The superficial resorption of cementum, which can occur in varying degrees during orthodontic treatment, has not been observed after rapid tooth movement[49,143]. There seems to be direct connection between the force magnitude and duration and the effect on dental tissues[12,13,14]. In this study, no measurable root resorption was found after RCR, which could be due to the short duration of force application.

Canines vitality after rapid tooth movement is a very critical issue. Postsurgical evaluation of patients who have been subjected to rapid orthodontic tooth movement after a *complete subapical osteotomy*, demonstrated that teeth within recently osteotomized segments show an overall decreased sensitivity. Teeth that are contiguous to an

osteotomy site are in greater jeopardy of becoming devitalized than those that are remote from it[20].

Regarding the periodontal health assessment, the results obtained in this study should be interpreted with care, as initial recordings were taken before surgery and before the placement of bands while the final recordings were taken after a surgical intervention which was followed by banding the teeth. The data on the pocket depth, attachment level, and crestal bone height changes (tables 7-6 and 7-7) demonstrate that the surgical procedure and both RCR modalities procedures were not excessively damaging to the periodontal tissues. Gingival recession was minimal and the interdental papillae were preserved, insuring a good post-treatment esthetic results (figures 7-1 and 7-2).

In the periodontal membrane distraction side, the tooth movement occurs gradually, thus simultaneous vascular regeneration occurs, protecting the vitality of the pulp[20]. In the alveolar bone distraction side, sudden movements after loosening of the osteotomized segment could severe blood vessels entering the pulpal canal[142]. Therefore, we recommend to prolong the latency period up to 7 days after the operation to allow the osteoclast-induced resorption and microcracks help undermine the osteotomized segment before distracting it.

In this study, although post-treatment electronic pulp testing of the canines showed negative response at the alveolar bone distraction side, laser Doppler flowmetry demonstrated that pulp vitality was maintained in both sides.

Regarding the periodontal health assessment, the results obtained in this study should be interpreted with care, as initial recordings were taken before surgery and before the placement of bands while the final recordings were taken after a surgical intervention

which was followed by banding the teeth. The data on the pocket depth, attachment level, and crestal bone height changes demonstrate that the surgical procedure and the distraction procedures were not excessively damaging to the periodontal tissues. Gingival recession was minimal and the interdental papillae were preserved, insuring a good post-treatment esthetic results. Our results in this regard are in concert with the results of previous investigations[21-24].

Orthodontic patients commonly experience a considerable amount of discomfort from orthodontic treatment. In a particular study[144], it was reported that 70% of the sample orthodontic patients had at least some degree of pain during the treatment. The fear of pain is one of the key factors that may discourage a patient from seeking orthodontic treatment[144]. In our study, patients generally experienced mild to moderate discomfort levels as indicated by the visual analogue scales. In the periodontal membrane distraction side, patients reported severe discomfort after appliance activation for three to four days. In addition they reported difficulty to turn the screw of the distraction appliance at the periodontal membrane distraction side. These two findings indicate the presence of excessive force acting on the teeth at that side.

9. References:

- 1- Norton LA, Burstone CJ: The biology of tooth movement, 2 ed, Boca Raton, N.Y., CRC Press, Inc., 1989
- 2- Oppenheim A: Tissue changes, particularly of the bone, incident to tooth movement, Trans Eur Orthodont Soc 8:11, 1911.
- 3- Schwarz AM: Tissue changes incidental to orthodontic tooth movement, Int J Orthodontia 18:331, 1932.
- 4- Talbot ES: Teeth irregularities and their surgical correction, Dent Cos 38:139-151, 1896.
- 5- Bichlmayr A: Über chirurgische Orthopädie bei Behandlung der Spätfälle (Treatment of adult cases with surgical orthodontics) Dtsch Zahnärztl Wschr 45:613-614, 1942.
- 6- Gantes B, Rathbun E, Anholm M: Effects on the Periodontium Following Corticotomy-Facilitated Orthodontics, J Periodont Apr:234-238, 1990.
- 7- Liou E, Shing Haung C: Rapid canine retraction through distraction of the periodontal ligament, Am J Orthod Dentofac Orthop 114(4):372-381 Discussion 381-382, 1998.
- 8- Ilizarov GA: The tension-stress effect on the genesis and growth of tissues, Part 2, Clin Orthop Rel Res 238:249-281, 1989.
- 9- Karaharju EO, Aalto K, Kahri A, *et al.*: Distraction bone healing, Clin Orthop & Rel Res 297:38-43, 1993.
- 10- Kallio TJ, Vaunhkonen MV, Peltonen JI, *et al.*: Early bone matrix formation during distraction, Acta Orthop Scand 65(4):467-471, 1994.
- 11- Blake M, Woodside DG, Pharoah MJ: A radiographic comparison of apical root resorption compared after orthodontic treatment with the edgewise and Speed appliances, Am J Orthod Dentofac Orthop Jul:76-84, 1995.
- 12- Reitan K: Initial tissue behaviour during apical root resorption, Angle Orthod 44:68-82, 1974.
- 13- Williams S: A histomorphometric study of orthodontically induced root resorption, Eur J Orthod 6:35-47, 1984.
- 14- Engstrom C, Granstrom G, Thilander B: Effect of orthodontic force on periodontal tissue metabolism: a histologic and biochemical study in normal and hypocalcemic young rats. Am J Orthod Dentofac Orthop 93:468-95, 1988.

- 15- Ketcham AH: A preliminary report of an investigation of apical root resorption of permanent teeth, *Int J Orthod* 12:97-127, 1927.
- 16- Hemley S: The incidence of root resorption of vital permanent teeth, *J Dent Res* 20:133-41, 1941.
- 17- Rudolph CE: An evaluation of root resorption during orthodontic treatment, *J Dent Res* 19:367-71, 1940.
- 18- Phillips JR: Apical root resorption under orthodontic therapy, *Angle Orthod* 25:1-12, 1955.
- 19- Goldson L, Henrikson CO: Root resorption during Begg treatment: A longitudinal roentgenologic study, *Am J Orthod* 68:55-66, 1975.
- 20- Duker J, Schilli W: Rapid orthodontics after subtotal osteotomy: Biologic foundation and clinical implications, In Bell WH: *Surgical correction of dentofacial deformities, new concepts*, volume III, ed. 9, Philadelphia, W.B. Saunders Company, 1985.
- 21- Kohler CA, Ramfjord SP: Healing of gingival mucoperiosteal flaps, *Oral Surg Oral Med Oral Path* 13:89, 1960.
- 22- Persson P: The regeneration of the marginal periodontium after flap operation, *Acta Odont Scand* 20:43, 1962.
- 23- Chamberlain AD, Garrett S, Renvert S, Egelberg J: Healing after treatment of periodontal intraosseous defects. IV. Effect of a non-resective versus a partially resective approach, *J Clin Periodontol* 12:525, 1985.
- 24- Gantes B, Rath E, Anholm M: Effects on the Periodontium Following Corticotomy-Facilitated Orthodontics. Case Reports, *Journal of Periodont* Apr:234-238, 1990.
- 25- Burstone CJ: Biomechanics of tooth movement, In: Krause BS ed, *Vistas in orthodontics*, Philadelphia: Lea & Febiger, 1964.
- 26- Ferreira SH, Nakamura M, Castro M: The hyperalgesic effects of protacyclin and prostaglandin E₂, *Prostaglandins* 16:31-37, 1978.
- 27- Higgs GA, Moncada S: Interactions of arachidonate products with other pain mediators, In: Bonica JJ, Lindholm U, Iggo A, eds: *Advances in pain research and therapy*, New York, Raven Press, 5:617-626, 1983.
- 28- Ngan P, Kess B, Wilson S: Perception of discomfort by patients undergoing orthodontic treatment, *Am J Orthod Dentofac Orthop* 96(1):47-53, 1989.

- 29- Gosney MBE: An investigation into factors which may deter patients from undergoing orthodontic treatment, Br J Orthod 12:133-138, 1985.
- 30- Johns M, Chan C: The pain and discomfort experienced during orthodontic treatment: a randomized controlled clinical trial of two initial aligning arch wires, Am J Orthod Dentofac Orthop 102:373-381, 1992.
- 31- Serogl HG, Klages U, Zentner A: Pain and discomfort during orthodontic treatment: causative factors and effects on compliance, Am J Orthod Dentofac Orthop 114(6):684-691, 1998.
- ✓ 32- Skogsborg C: Die permanente Fixierung der Zähne nach orthodontischer Behandlung (Permanent fixed retention of the teeth after orthodontic treatment) Vjschr Zahnheilk 4:278-293, 1926.
- 33- Bichlmayr A: Chirurgische Kieferorthopädie und das Verhalten des Knochens und der Wurzelspitzen nach derselben (The position of the root apices and the surrounding bone after surgical orthodontics) Dtsch Zahnärztl Z 34:835-842, 1931.
- 34- Bichlmayr A: Zur Spätbehandlung der Kieferanomalien (Late treatment of jaw abnormalities) Dtsch Zahnärztl Z 45:15-23, 1942.
- 35- Bichlmayr A: Über chirurgische Orthopädie bei Behandlung der Spätfälle (Treatment of adult cases with surgical orthodontics) Dtsch Zahnärztl Wschr 45:613-614, 1942.
- 36- Spanier F: Prognathie-Operationen (Prognathic operations) Z Zahnärztl Orthop 24:76-85, 1932.
- 37- Schönwald R: Die chirurgische Kieferorthopädie Bichlmayr (Osteotomie) (Surgical orthodontics, Bichlmayr's Osteotomy) Dtsch Zahnärztl Wschr 37: 407-309, 1934.
- ✓ 38- Neumann D: Die Bichlmayrsche Keilresektion bei der kieferorthopädischen Spätbehandlung (Bichlmayr's resection in late orthodontic treatment) Fortschr Kiefer Gesichtschir 1: 205-210, 1955.
- 39- Köle H: Corticalisschwächung zur Unterstützung bei der Kieferorthopädischen Behandlung (Corticotomy-supported orthodontic treatment) Fortschr Kiefer Gesichtschir 4: 208-212, 1958.
- 40- Köle H: Chirurgische Kieferorthopädie am Alveolarkamm (Surgical orthodontics at alveolar ridge) Öst Z Stomat 56: 57-73, 1959.
- 41- Dal Pont G: La corticomia di Köle applicata al raddrizzamento immediato dei denti. Riv Ital Stomat 18: 415-426, 1963.

- 42- Dal Pont G: Su una nuova tecnica di raddrizzamento immediato dei denti a mezzo di trapianto alveolodentale pedunculatolo. *Minerva Stomat* 14: 110-116, 1965.
- 43- Edland A, Subrtova J: Corticotomy-cooperation of the oral surgeon and the orthodontist. *Proceedings of the Second International Conference on Oral Surgery, Copenhagen, 2: 339-344, 1965.*
- 44- Horvath L. Rehák R: Kieferchirurgische Massnahmen zur Unterztützung von Spätregulierungen (Surgical measures to support long term stability) *Dtsch. Zahnärztl Z* 16: 525-529, 1961.
- 45- Byloff-Clar H: Comparative histologic studies of late cases treated with and without corticotomy, *Fortschr Kieferorthop* 27(2):204-219,1966.
- 46- Byloff-clar H: Behandlung mit aktiven Platten mit und ohne Corticotomie bei Spatfallen (Jugindlichen) (Treatment of delayed (juvenile) cases using activators with and without corticotomy, clinical and histologic study), *Stoma (Heidelb)* 20(4):134-141, 214-225, 277-286, 1967.
- 47- Subrtova I, Subrt I:Correction of the upper dental arch anomalies of the class 2 div.1 by means of corticotomy, *Cesk Stomatol* 68(2):139-143, 1968.
- 48- SubrtovaI, Edlan A, Subrt T: Corresction of upper dental arch in Angle class 2 cases by means of corticotomy, *Dtsch Stomatol* 20(3):181-185, 1970.
- 49- Converse JM, Horowitz SL: The surgical orthodontic approach to the treatment of dentofacial deformities. *Am J Orthod* 55: 217-243, 1969.
- 50- Bell WH, Condit CL: Surgical-orthodontic correction of adult bimaxillary protrusion, *J Oral Surg* 28: 578-590, 1970.
- 51- Tenebaum M: Corticotomy, a surgical-orthodontic method, *Ortodoncia* 34(68):162-170,1970.
- 52- Isiksal E: Corticotomy and orthodontic treatment in maxillary endognathy and protrusion with diastema, *Istanbul Univ Dishekim Fak Derg* 3(4):525-532, 1972.
- 53- MachtensE, Karwetzky R, Meisel HH: Corticotomy and wedge-shaped tongue excision as supporting therapy in late orthodontic cases, *ZWR* 81(22):1070-1074, 1972.
- 54- Subrtova I, Subrt I: Reversed occlusions in the frontal region of teeth treated by corticotomy, *Cesk Stomatol* 74(3):206-210, 1974.
- 55- Duker J: Experimental animal research into segmental alveolar movement after corticotomy, *J Maxillofac Surg* 3(2):81-84, 1975.

- 56- Aboul-Azm SF, Khalil AF, Abdel-Dayem H: Evaluation of anterior maxillary corticotomy as a line of treatment for maxillary protrusion and ostectomy technique, *Alex Dent J* 2)3_:115-127, 1977.
- 57- Generson RM, Porter JM, Zell A, *et al.*: Combined surgical and orthodontic management of anterior open bite using corticotomy, *J Oral Surg* 36(3):216-219, 1978.
- 58- Itoh T, Nakajima M, Arita S, *et al.*: Experimental study on the tooth movement with corticotomy procedure, *Nippon Kyosei Shika Gakkai Zasshi* 40(1):92-105, 1981.
- 59- Nakanishi H: Experimental study on artificial tooth movement with ostetomy and corticotomy, *Shikwa Gakuho* 82(2):219-252, 1982.
- 60- Tuinzing DB, Dorenbos J: Corticotomy, surgical aspects of orthodontics, *Ned Tijdschr Tandheelkd* 93(5):175-176, 1986.
- 61- Anholm JM, Crites DA, Hoff R, *et al.*: Corticotomy-facilitated orthodontics, *CDA J* 14(12):7-11, 1986.
- 62- Kawai S, Kawai M, Nakamura A, *et al.*: Orthodontic uprighting of mandibular second molars, *Fukuoka Shika Daigaku Gakki Zasshi* 17(1):75-86, 1990.
- 63- Kerdvongbundit V: Corticotomy-facilitated orthodontics, *J Dent Assoc Thai* 40(6):284-291, 1990.
- 64- Benech A, *et al.*: The ortho-surgical correction of two cases of angle class II div1, *Minerva Stomatol.* 41(10):475-480, 1992.
- 65- Kawakami T, *et al.*: Histological suture changes following retraction of the maxillary anterior bone segment after corticotomy, *Endod Dent Traumatol.* 12(10):38-43, 1996.
- 66- Hofer O: Die operative Behandlung der alveolaren Retraktion des unterkiefers und ihre Anwendungsmöglichkeit fur Prognathie und Mikorgenie, *Dtsch Zahn Mund Kieferheilk* 9:121-132, 1942.
- 67- Angell EH: Treatment of irregularities of permanent or adult teeth, *Dent Cos* 1:540-4:599-600, 1860.
- 68- Timms DJ: *Rapid Maxillary Expansion*, ed 1, Illinois, 1881, Quintessence Puplishing Co.
- 69- Goddard CL: Separation of the superior maxilla at the symphysis, *Dent Cos* 35:880-882, 1893.

- 70- Cope JB, Samchukov ML, Cherkashin AM: Mandibular distraction osteogenesis: A historic perspective and future directions, *Am J Orthod Dentofacial Orthop* 115:448-460, 1999.
- 71- Codivilla A: The means of lengthening in the lower limb, muscles and tissues which are shortened through deformity, *Am J Orthop Surg* 2:353-369, 1905.
- 72- Abott LC, Saunders JB: The operative lengthening of the tibia and fibula: a preliminary report in the further development of principles and technique, *Ann Surg* 110:961-991, 1939.
- 73- Anderson WV: Leg lengthening, *J Bone Joint Surg (Br)* 34:150-152, 1952.
- 74- Coleman SS, Noonan TD: Anderson's method of tibial lengthening by percutaneous osteotomy and gradual distraction, *J Bone Joint Surg* 49A:263-279, 1967.
- 75- Ilizarov GA, Devyatov AA, Karnerim VK: Plastic reconstruction of logitudinal bone defects by means of compression and subsequent distraction, *Acta Chir Plast* 22:32-41, 1980.
- 76- Metav I: Thumb reconstruction in children through metacarpal bone lengthening, *Plast Reco nst Surg* 64:665-669, 1979.
- 77- Paneva-Holevich E, Yankov E: A distraction method for lengthening of the finger metacarpals: a preliminary report. *J Hand Surg* 5:160-167, 1980.
- 78- Kazanjian VH: The interrelationship of dentistry and surgery in the treatment of deformities of the face and jaws, *Am J Orthod Oral Surg* 27:10-30, 1941.
- 79- Crawford MI: Selection of appliances for typical facial fractures, *Oral Surg Oral Med Oral Path* 1_442-451, 1948.
- 80- Snyder CC, Levine GA, Swanson HM: Mandibular lengthening by gradual distraction, *Plast Reconstr Surg* 51:506-508, 1973.
- 81- Michieli S, Miotti B: Controlled gradual lengthening of the mandible after osteotomy. *Minerva Stomatol* 25:77-88, 1976.
- 82- Kutsevliak VI, Sukachev VA: Distraction of the mandible in an experiment, *Stomatologiya Mosk* 63(4):13-15, 1984.
- 83- Constantino PD, Shybut G, Friedman CD, *et al.*: Segmental mandibular regeneration by distraction osteogenesis, *Arch Otolaryngol Head Neck Surg* 116:535-545, 1990.
- 84- Karaharju-Suvanto T, Karaharju EO, Ranta R: Mandibular distraction, *J Craniomaxillofac Surg* 18:280-283, 1990.

- 85- Karp NS, Thorne CHM, McCarthy JG: Bone lengthening in the craniofacial skeleton, *Ann Plast Surg* 24:231-237, 1990.
- 86- Phillips JH, Forest CR, Gruss JS: Current concepts in the use of bone grafts in facial fractures, *Clin Plast Surg* 19:41-58, 1992.
- 87- Gantous A, Phillips JH, Catton P, *et al.*: Distraction osteogenesis in the irradiated canine mandible, *Plast Reconstr Surg* 93_164-168, 1994.
- 88- Komuro Y, Takato T, Harii K, Yonemura Y: The histologic analysis of distraction osteogenesis of the mandible in rabbits, *Plast Reconstr Surg* 94(1):152-9, 1994.
- 89- Altuna G, Walker DA, Freeman E: Rapid orthopedic lengthening of the mandible in primates by sagittal split osteotomy and distraction osteogenesis: a pilot study, *Int J Adult Orthodon Orthognath Surg* 10(1):59-64, 1995.
- 90- Rowe NM, Mehrara BJ, Dudziak ME, *et al.*: Rat mandibular distraction osteogenesis: Part I. Histologic and radiographic analysis, *Plast Reconstr Surg* 102(6):2022-32, 1998.
- 91- Glat PM, Staffenberg DA, Karp NS, *et al.*: Multidimensional distraction osteogenesis: the canine zygoma, *Plast Reconstr Surg* 94(6):753-8, 1994.
- 92- Rachmiel A, Potparic Z, Jackson IT, *et al.*: Midface advancement by gradual distraction, *Br J Plast Surg* 46(3):201-7, 1993.
- 93- Rachmiel A, Jackson IT, Potparic Z, *et al.*: Midface advancement by gradual distraction : a follow-up study, *J Oral & Maxillofac Surg* 53(5):525-9, 1995.
- 94- Block MS, *et al.*: Use of distraction osteogenesis for maxillary advancement: preliminary results, *J Oral Maxillofac Surg* 52(3):282-286, discussion 287-288, 1994.
- 95- Cohen SR, *et al.*: Maxillary-Midface distraction in children with cleft lip and palate: a preliminary report, *Plast Reconstr Surg* 99(5):1421-1428, 1997.
- 96- Molina F, *et al.*: Maxillary distraction: aesthetic and functional benefits in cleft lip-palate and prognathic patients during mixed dentition, *Plast Reconstr Surg* 101(4):951-963, 1998.
- 97- Polly JW, *et al.*: Rigid external distraction: its application in cleft maxillary deformities, *Plast Reconstr Surg* 102(5): 1360-1372, 1998.

- 98- Figura AA, *et al.*: Management of severe cleft maxillary deficiency with distractionosteogenesis: procedur and results, Am J Orthod Dentofacial Orthop 115(1):1-12, 1999.
- 99- Persing JA, Babler WJ, Nagorsky MH, *et al.*: Skull expansion in experimental craniosynostosis. Plast Reconstr Surg 78:594-603, 1986.
- 100- Ilizarov GA: The tension-stress effect on the genesis and growth of tissues, Part 1, Clin Orthop Rel Res 238:249-281, 1989.
- 101- Remmler D, McCoy FJ, O'Neil D, *et al.*: Osseous expansion of the cranial vault by craniostasis, Plast Reconstr Surg 89:787-797, 1992.
- 102- Barone CM, *et al.*: Distraction of the frontal bone outside the cranial plane: a rabbit model, J Craniofac Surg 51(6):652-660, 1993.
- 103- Pittman T, *et al.*: Cranial vault moulding by the transcutaneous activation of implanted magnets, Pediatr Neurosurg 27(2):78-83, 1997.
- 104- Rinehart G, *et al.*: Cranial vault expansion using transcutaneously activated magnetic implants, Pediatr Neurosurg 28(6):293-299, 1998.
- 105- Fink B, Krieger M, StraussJM, *et al.*: Osteoneogenesis and its influencing factors during treatment with the Ilizarov method, Clin Orthop & Rel Res 323:261-271, 1996.
- 106- Yasui N, Kojimoto H, Saski K, *et al.*: Factors affecting callus distraction in limb lengthening, Clin Orthop 293:55-60, 1993.
- 107- Delloye C, Delefortrie G, Coutelier L, *et al.*: Bone regenerate formation in cortical bone during distraction lengthening, Clin Orthop 250:34-42, 1990.
- 108- Cojimoto H, Yasui N, Goto T, *et al.*: Bone lengthening in rabbits by callus distraction, J bone Joint Surg 70B:543-549, 1988.
- 109- White SH, Kenwright J: The timing of distraction of an osteotomy, J Bone Joint Surg 72B:356-362, 1990.
- 110- White SH, Kenwright J: The importance of delay in the distraction of osteotomies, Orthop Clin North Am 22:569-579, 1991.
- 111- Aronson J, Shen X: Experimental healing of distraction osteogenesiscomparing metaphyseal with diaphyseal sites, Clin Orthop 301:25-30, 1994.
- 112- Wagner H: Operative legthening of the femur, Clin Orthop 136: 125-142, 1978.
- 113- Ilizarov GA: Transosseous osteosynthesis, Berlin, Springer-Verlag, 1992.

- 114- Paley D: Problems, obstacles and complications of limb lengthening by the ilizarov technique, Clin Orthop 250:81-104, 1990.
- 115- Fischgrund J, Paley D, Suter C: Variables affecting time of bone healing during limb lengthening, Clin Orthop 301:31-37, 1994.
- 116- Brutscher R, Rahn BA, Ruter A, *et al.*: The role of corticotomy and osteotomy in the treatment of bone defects using the Ilizarov technique, J Orthop Trauma 7:261-269, 1993.
- 117- Ekstrom C, Henrikson CO, Jensen R: Mineralization in the midpalatal suture after orthodontic expansion, Am J Orthod 71:449-455, 1977.
- 118- Frierson M, Ibrahim K, Boles M, *et al.*: Distraction osteogenesis, a comparison of corticotomy techniques, Clin Orthop & Rel Res 301:19-24, 1994.
- 119- Panjaba MM, Lindsey RW, Walter SD, *et al.*: Correlation of radiographic analysis of healing fractures with strength: a statistical analysis of experimental osteotomies, J Orthop Res 3:212-218, 1985.
- 120- Panjaba MM, Lindsey RW, Walter SD, *et al.*: The clinician's ability to evaluate the strength of healing fractures from plain radiographs, J Orthop Traum 3:29-32, 1989.
- 121- Cobo JM, Vijande M, Suarez-Quintanilla D: Evaluation of maxillary disjunction with bone densitometry, J Clin Orthod Feb:107-110, 1992.
- 122- Kazazoglu E, Heath MR, Mehmet J: A digital X-ray unit: radiovisiography, Gen Dent Treat (Inst.20) 2.7.4.:1-9, 1992.
- 123- Goaz PW, White SC: Oral radiology: principles and interpretation, D.C., C.V. Mosby Company, 1987.
- 124- Lurie AG: Risk/benefit considerations in orthodontic radiology: an interview, J Clin Orthod Jul:469-484, 1981.
- 125- Gazelius B, Olgart L, Edwall L: Non-invasive recording of blood flow in human dental pulp, Endodontics & Dent Traumatology 2:219-221, 1986.
- 126- Kim S, Liu M, Markowitz K, *et al.*: Comparison of pulpal blood flow in dog canine teeth determined by laser Doppler and the 133 Xenon washout methods, Arch Oral Biol 35:411-413, 1990.
- 127- McDonald F, Pitt Ford TR: Blood flow changes in permanent maxillary canines during retraction, Eur J Orthod 16:1-9, 1994.

- 128- Huskisson EC: Visual analogue scale, In :Melzack R, ed. Pain measurement and assessment, New York: Raven Press, pg186-187, 1983.
- 129- Scott J, Huskisson EC: Accuracy of subjective measurements made with or without previous scores: an important source of error in serial measurements of subjective states, *Ann Rheum Dis* 38:558-559, 1979.
- 130- Brunner UH, Cordy J, Scheiberer L, *et al.*: Force required for bone segment transport in the treatment of large bone defects using medullary nail fixation, *Clin Orthop & rel Res* 301:147-155, 1994.
- 131- Hyodo A, Kotschi H, Kambic H, *et al.*: Bone transport using intramedullary fixation and a single flexible traction cable, *Clin Orthop & Rel Res* 325:256-268, 1996.
- 132- Fisher E, Staffenberg DA, McCarthy JG, *et al.*: Histopathologic and biochemical changes in the muscles affected by distraction osteogenesis of the mandible.
- 133- Castelli WA: Dempster WT: the periodontal vasculature and its responses to experimental pressures, *J Am Dent Assoc* 70:890-905, 1965.
- 134- Gaudet EL,Jr: Tissue changes following Begg root torque, *Am J Orthod* 58:164-178, 1970.
- 135- Moyers RE: The periodontal membrane in orthodontics, *J Am Dent Assoc* 40:22-27,1950.
- 136- Reitan K: The initial tissue reaction incident to orthodontic tooth movement, *Acta Odontol Scand Suppl* 6, 1951.
- 137- Burstone CJ, Pryputniewicz RJ: Holographic determination of centers of rotation produced by orthodontic forces. *Am J Orthod* 77: 396-409, 1980.
- 138- Marc M, Bulcke V, Burstone CJ, *et al.*: Location of centers of resistance for anterior teeth during retraction, *Am J Orthod Dentofac Orthop* May:375-384, 1987.
- 139- Burstone CJ: The biomechanics of the tooth movement, In:Kraus BS, Reidel RA, ed, *Vistas in Orthodontics*, Philadelphia, Lea & Febiger, 1962.
- 140- Hixon EH, Gallow GE, McDonald HW, *et al.*: Optimal force, differential force and anchorage, *Am J Orthod* 55:417-457, 1969.

- 141- Bell WH: Revascularization and bone healing after anterior maxillary osteotomy: a study using adult Rhesus monkeys. *J Oral Surg* 27:249-255, 1969.
- 142- Proffit WR, Fields HW: Contemporary orthodontics, 2 ed, St.Louis-Missouri, Mosby, 1993.
- 143- OppenheimA: Human tissue response to orthodontic intervention of short and long duration, *Am J Orthod Oral Surg* 28:263-301, 1942.
- 144- Oliver RG, Knappman YM: Attitudes to orthodontic treatment, *Br J Orthod* 12:179-188, 1985.



Autobiography:

I was born in 1973 in S.A. My elementary education was received in S.A. I completed my high school in 1990 from Khamis Mushait High School. In 1996, I completed my B.D.S. from the University of Jordan. In 1997, I was accepted for the orthodontics master program in Marmara University, Istanbul, Turkey.

SAĞLIK BİLİMLERİ ENSTİTÜSÜ MÜDÜRLÜĞÜ'NE

Yüksek Lisans öğrencisi Mohannad AL-HAJJain, çalışması jürimiz tarafından Ortodonti Anabilim Dalı İngilizce Ortodonti Yüksek Lisans Programı tezi olarak uygun görülmüştür.

İMZA

Tez Danışmanı : Yrd.Doç.Dr.Sibel BİREN
Üniversitesi : Marmara

Üye : Prof.Dr.Nejat ERVERDİ
Üniversitesi : Marmara

Üye : Doç.Dr.Nazan KÜÇÜKKELEŞ
Üniversitesi : Marmara

Üye : Doç.Dr.Tülin ARUN
Üniversitesi : Marmara

Üye : Yrd.Doç.Dr.Ahmet KELEŞ
Üniversitesi : Marmara

ONAY

Yukarıdaki jüri kararı Enstitü Yönetim Kuruluna/...../199.... tarih ve sayılı kararıyla onaylanmıştır.

Prof.Dr.Sevim ROLLAS
Müdür