

**Evaluation of Maxillary Canine Retraction using a
distraction device - An *in vivo* study**

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CERTIFICATE

This is to certify that this dissertation titled “**EVALUATION OF MAXILLARY CANINE RETRACTION USING A DISTRACTION DEVICE – AN *IN VIVO* STUDY**” is a bonafide record of work done by **Dr. V. K. SHAKEEL AHMED** under my guidance during his postgraduate study period between 2002 - 2005.

This dissertation is submitted to **THE TAMIL NADU Dr. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the degree of **Master of Dental Surgery in Branch V –Orthodontia**.

It has not been submitted (partially or full) for the award of any other degree or diploma.

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INTRODUCTION

Conventional orthodontic tooth movement takes place due to a biological cascade of resorption and apposition secondary to mechanical forces. Individual factors such as the optimum force, turnover in the periodontal ligament and bone metabolism play a vital role in the determination of the rate of orthodontic tooth movement.

Typical tooth movement occurs after a moderate, continuous force. The orthodontic response is divided into three elements of tooth displacement.

1. Initial strain occurs in about 1-3 days because of periodontal ligament displacement (strain), bone strain and extrusion.
2. A variable lag phase, usually last 2 to 3 weeks but may be as long as 10 weeks, in which undermining resorption removes bone adjacent to crestal areas in the periodontal ligament; and
3. After undermining resorption restores vitality to remove areas of the hyalinized periodontal ligament, tooth movement enters secondary, or progressive tooth movement phase. Frontal resorption in the periodontal ligament and initial remodeling events in the cortical bone ahead of the advancing tooth allows for progressive tooth movement at a relatively rapid rate.

The rate of osteogenesis during tooth retraction limits the tooth movement to a maximum of 1 to 1.5mm per month. Conventional orthodontic mechanics achieve space closure at the rate of 1mm per month.

When space closure exceeds the rate of 1.5mm per month, undesirable effects are encountered, this may manifest as loss of torque. Torque is lost especially in the upper incisor region. Upper incisors become too upright at the end of space closure, with spaces distal to the canine, and results in an unaesthetic appearance and it is difficult to regain the lost torque. Rapid mesial movement of upper molar leads to over hanging palatal cusps, which results in functional interferences. Rolling in of lower molars can also occur with tipping and extrusion of the distal cusps. Due to lack of tip control the canine, premolars, and molars will not interdigitate properly leading to an open bite. Soft tissue hyperplasia as a result of too rapid space closure may prevent proper space closure, or causes re-opening of the extraction space.

Canine retraction after first premolar extraction is a very common orthodontic procedure. If this is to be done as a bodily distal movement, a fixed appliance is necessary to produce a moment on the tooth in addition to the distal driving force.

A combination of a force and moment acting at the bracket is needed because a force alone would have to pass through the center of resistance of the root to produce a desired translatory tooth movement. However, this involves the risk of frictional binding of the tooth with subsequent delay or arrest of the tooth movement. Another weakness that allows the canine to tip during its distal movement is the flexibility of the arch wire in the span between the anterior and posterior teeth. Because of the reactive forces from the moment, the arch wire will bow and no longer constitute a straight line along which the canine can slide, which result in tipping of canine. Not only

is a pure bodily distal movement of the canine difficult to achieve during retraction, the canine also tends to rotate because the force application is not through the center of resistance of the tooth in the labiolingual direction either, a moment is necessary to counteract tooth rotation.

Canine retraction is accomplished through various modalities: -

SLIDING MECHANICS : coil springs, latex elastics, synthetic elastic modules, magnets.

SEGMENTAL MECHANICS : Ricketts maxillary canine retractor, Burstone T loop, Poul Gjessing-spring.

EXTRA-ORAL FORCES : “J” hook headgear.

Canine retraction is a slow process and is heavy on anchorage requirement. It takes 6 to 8 months just to retract the canine into the premolar extraction site. A novel method of reducing the time and the anchorage demands during canine movement is by employing the principle of distraction osteogenesis.

Distraction osteogenesis is a process of growing new bone by mechanical stretching of the pre-existing soft tissue. The technique in distraction involves mechanical stretching of the reparative bone tissue by distraction device through an osteotomy or corticotomy site. With this technique new bone is generated in the site of osteotomy or corticotomy at the rate of 1mm per day.

Distraction osteogenesis is a gradual bone-lengthening technique that was first introduced in 1905 by Codivilla in Bolgna, Italy. It was popularized by the extensive clinical and research studies of Illizarov in Russia in the

1970. External devices were initially used for distraction osteogenesis. The devices for intra-oral applications were introduced shortly afterward and newer applications have been fostered. Intraoral distraction devices have been used for lengthening, widening and augmentation to correct several skeletal problems.

A recent innovative use of distraction osteogenesis in the field of orthodontic tooth movement is the application of the principle of distraction to move individual tooth segments rapidly thus reducing orthodontic treatment time.

To shorten the amount of time necessary for orthodontic tooth movement, various attempts have been made. In 1998 Liou and Huang presented a method of rapid canine retraction after the extraction of the first premolar through the weakening of the interseptal bone. The described canine tooth retraction technique was actually achieved through the stretching of the periodontal ligament. (Periodontal ligament distraction)²⁰.

This attractive application of distraction through the periodontal ligament had some short comings viz, It has been shown experimentally that decreased vascular blood supply occurs when the magnitude of tensile force is extended it results in cell death within the vicinity of the stretched fibers. Resorption of Sharpey's fibers, vascular invasion of cells into the periodontal membrane, resorption of alveolar bone, and reduction in alveolar bone thickness and height are also inevitable in the region of tension generated by this appliance.

Dento-alveolar distraction of the canine:

With the present technique of rapid orthodontic canine retraction through distraction osteogenesis by Reha-kisnici and Haluk-iseri, the **dentoalveolus** itself is designed as a bone transport segment for posterior

movement. Vertical osteotomies were performed around the root of canine teeth, followed by splitting of spongy bone around it. Therefore the design of surgical technique itself does not rely on periodontal stretching, which obviates overloading and stress accumulation in this tissue, which was the drawback of the previous attempts of canine distraction through the periodontal ligament ⁵⁸.

Reha-kisnici and Haluk-iseri in their study established a new approach to reduce the overall orthodontic treatment time by means of dentoalveolar distraction osteogenesis.

Hence this study was conducted to evaluate the dentoalveolar changes during rapid orthodontic canine retraction using a custom-made tooth borne intraoral distraction device.

REVIEW OF LITERATURE

CANINE RETRACTION

George Andreasen and David Zwanziger et al (1980) ²³ subjected canines and first molars to two ranges of forces, 100 to 150 grams and 400 to 500 grams, in 14 female patients using sliding mechanics on 0.018-inch continuous stainless steel round wires. They found no optimal force but rather that both teeth moved simultaneously and moved more with the larger force.

Carlos Ayala Perez et al (1980) ¹⁴ analyzed the distribution of force transmitted to the alveolar bone and surrounding structure by means of photoelastic visualization, utilizing J-hook headgear for maxillary canine retraction. A three-dimensional photoelastic model was reproduced from a human skull to permit an analysis of the effects of forces. Three different vectors of force, representing high, medium and low-pull headgear were

applied. They concluded that High-pull headgear produced the least tipping effect during canine retraction.

Huffman and Way et al (1983)¹⁸ conducted a clinical study to compare the amount and rate of tooth movement and tipping of canines on 0.016-inch and 0.020-inch with a continuous force of 250 grams on 0.022" slot brackets. Over a 10-week observation period, the mean amount of canine retraction along 0.016-inch wire was 3.37mm at the rate of 1.37mm/month, while that along the 0.020-inch wire was 2.49mm at the rate of 1.20mm/month was observed. The mean amount of tipping on the 0.016-inch wire was 5.3°, while that on the 0.020-inch wire was 1.7°.

Quinn and Yoshikawa et (1985)⁶¹ pointed out that the use of incisors as stable reference points to measure canine retraction and anchorage loss may introduce a systematic error, because, some posterior repositioning of the incisors occurs as the canine are retracted. This, they suggested, would lead to underestimation of canine retraction and over estimation of anchorage loss. They suggested that increasing the root surface area of the anchorage unit could enhance anchorage.

Andrew Sonis et al (1986)⁸ compared the rate of canine retraction with elastomeric auxiliaries and elastic threads. The forces initially applied were between 350-400 grams. Patients were seen at 3-week intervals to measure. There was no significant difference between the rates of canine retraction.

Peter Zeigler and Ingervall et al (1989)⁵⁶ compared the efficiency of maxillary canine retraction by means of sliding mechanics using a 0.018-inch stainless steel wire in a 0.018-inch bracket slot with an elastic chain, with that using a spring designed by Gjessing. Measurements were made in the mouth and on photographs of dental casts. The rate of canine retraction with sliding mechanics was 1.4mm/month while that with the Gjessing

spring was 0.5mm faster. These values refer to the movement of the crown of the canine, the root moving lesser due to the simultaneous distal tipping of the canines. The amount of tipping for 6mm of canine retraction was about 4.5° for the Gjessing spring and 8.5° for the sliding mechanics. The average distopalatal canine rotation during 6mm of retraction was 24° for sliding mechanics and 30° for the Gjessing spring.

Chandra et al (1990)⁵⁴ introduced the sliding tube appliance for maxillary canine retraction, which was a modified removable appliance and had many advantages over the other removable appliances.

Andrew Sonis et al (1994)⁹ compared the rate of canine retraction using sentalloy nickel titanium coil springs and latex elastics. He observed that on using approximately 150grams of force, Niti coil springs produced about 0.51 mm per week of retraction while latex elastics produced 0.27mm /week and concluded that closed coil springs produced nearly twice as rapid a rate of tooth movement as conventional elastics at about the same force level.

Dincer and Iscan et al (1994)¹⁶ compared the effects of the PG springs, with a sectional arch including a reverse closing loop to retract the canine on 12 patients with a mean age of 25 years. The wire used was 0.016”x 0.022”stainless steel archwire in a 0.018” edgewise slot. The PG spring was applied to the left side and the sectional arch on the right side. The force delivered on either side was 150 grams. The PG was used for a mean period of 6 months, whereas the sectional arch was used for a mean period of 7.75months. They reported that.

1. The average anchorage loss in the upper arch was 1.63mm on the PG spring and 2.46mm on the reverse closing loop archside.
2. The rate of retraction in the maxillary arch was 0.85mm/month on the PG spring and 0.15mm/month on the reverse closing loop side.

3. Distal tipping with the PG spring was 3.3° and that with the reverse closing loop was 5.4°.

Daskalogiannakis and Mclachlan et al (1996)³⁵ compared the rate of canine retraction using rare earth magnets, which provided a constant force, with a vertical loop, which provided a force rapidly declining in magnitude. They reported a mean rate of retraction of 0.638mm/28 days on the interrupted for side and .22mm/2 days on the magnet side.

Pilon et al (1996)³⁰ demonstrated that, on application of orthodontic force, there was an initial minimal tooth movement produced due to movement of the tooth within its socket. This was followed by a period of no tooth movement probably associated with hyalinization of the periodontal ligament. This phase lasted up to a maximum of 35 days and was independent on the applied force magnitude. No significant difference was found either in the rate of tooth movement or amount of anchorage loss, when forces of 50, 100 and 200 grams were used.

Lotzof and Fine (1996)⁴¹ compared the rate of maxillary canine retraction and anchorage with two different, pre-adjusted bracket system. “Tip edge” and “A” company straight wire Roth 0.22” prescription in a sample of 12 patients in the age range of 12-15 years. Retraction was done on 0.018-inch stainless steel archwire using an elastic chain with 200 grams of force. Measurements were done in the mouth and on dental casts. The anterior palatal vault was used as a stable reference point to determine anchorage loss. The mean rates of retraction were 1.88mm/3 week period and 1.63mm/3 week for the “Tip edge” and “A” company brackets respectively. The values represent the movement of the crowns of the maxillary canines. The mean anchorage loss was 1.71mm for the “Tip edge” brackets and 2.33mm for the “A” company brackets.

Darendeliler et al (1997)⁴ tested the clinical use of a new spring, the drum spring (DS) retractor that applied a constant and continuous force without the need for reactivation. They also compared the effect of the drum spring retractor and a traditional pull coil retractor system on the rate of upper canine retraction in a sample of 15 patients. The DS retractor was successful without any reactivation, and the traditional pull coil system provided a more rapid canine movement. Canine retraction occurred faster in adolescent than in adults.

Rajich et al (1997)⁵⁰ investigated intra-arch mechanics using differential movement for anchorage control while retracting maxillary canine and found an anchorage loss of 0.7mm during canine retraction. They investigated canine and molar movement on the plaster casts using palatal rugae as stable landmarks. They pointed out that without adjunctive anchorage control appliances, 1.6 to 4mm of anchorage loss while retracting canine. With an anchorage controlling appliance upto 2.4mm of anchorage loss has been reported during maxillary canine retraction.

Hasler et al (1997)²⁷ compared the rate of maxillary canine retraction into healed and recent extraction sites, using Gjessing retraction springs. They concluded that the canine on the recent extraction side move faster than that on the healed side, but also tipped some what more. They say that this might be due to the insufficient movement to force ratio of the spring, since the center of resistance of the tooth might be located further apically and bone distal to canine being denser near the apex than the marginal area.

Liou and Huang et al (1998)²⁰ proposed a new concept of “distracting the periodontal ligament” to elicit rapid canine retraction in 3 weeks. They coined the term “Dental Distraction” for this procedure. At the time of first premolar extraction, the interseptal bone distal to the canine was undermined

with a bur, grooving vertically inside the extraction socket along the buccal and lingual sides and extending obliquely towards the socket base. Then a tooth-borne, custom-made intra-oral distraction device was placed to retract the canine into the extraction space. Both upper and lower canines were distracted 6.3 into the extraction space within 3 weeks. New alveolar bone was generated and remodeled rapidly in the mesial periodontal ligament of the canine during and after distraction. It became indistinguishable from the native alveolar bone 3 months after distraction. During the distraction, 73% of the first molar did not move mesially and 27% of them moved mesially less than 0.5mm within 3 weeks. No periodontal defect or endodontic lesion was observed throughout and after distraction. The radiographic examination revealed that apical and lateral surface root resorption of the canines was minimal. They concluded that the periodontal ligament could be distracted to elicit rapid canine retraction with complications.

Liou and Huang et al (2001) ²¹ in his rapid canine retraction using distraction of the periodontal ligament has reported on the earliest use of a screw similar to distraction device by Farrar et al as early as 1876. He reported use of his “positive system”, a special screw utilized to retract canine into the space left after extraction of first premolar. The screw was activated twice daily at the rate of 0.42mm per day. He found no perceptible change in the position of the posterior teeth, suggesting that no anchorage loss occurred.

Liou and Huang et al (2001) ²¹ in his rapid canine retraction using distraction of the periodontal ligament has reported on the earliest use of a screw similar to distraction device by Angle et al as early as 1887. He developed a retraction screw to move the canine distally after extraction of

the first premolar. The screw mechanics remained the most commonly used appliance for moving teeth until Angle's introduction of the edgewise appliance.

Jason Cope and Samchukov et al (2001)³³ in his history of craniofacial distraction osteogenesis has reported on the earliest use of a surgical technique and screw similar to distraction device by Kole et al as early as 1959. He developed the predecessor of the rapid canine distraction method. He suggested the use of corticotomy technique to assist in moving teeth, either individually or as a group, with orthodontic mechanics. Eight days after surgery, an orthodontic expansion screw was activated twice (0.5mm) in the first week and once (0.25mm) during subsequent weeks, until the final tooth position was achieved within 8 to 10 weeks and allowed 6 months for bone consolidation using retention appliance.

Reha Kisinisci and Haluk Iseri et al (2002)⁵⁸ presented a technique of "rapid orthodontic canine retraction", to reduce the overall orthodontic treatment time by means of dentoalveolar distraction osteogenesis. The dentoalveolar segment is designed as "bone transport segment" for posterior movement. Eleven patients undergoing orthodontic treatment with bilateral first premolar extractions and subsequent bilateral canine tooth distalization underwent osteotomy around the canine tooth. The first premolar was extracted, and the buccal bone was carefully removed. After wound closure, a special orthopedic device was mounted and cemented to the first molar and canine teeth. Distraction was started the same day at the rate of 0.4mm twice a day and continued until canine tooth moved posteriorly and made contact with the second premolar in 8 to 12 days. The distraction rate and the device were well tolerated by all patients. The device was then removed and orthodontic therapy was continued with fixed appliances. Result suggests

there was no anchorage loss in the second premolar and first molar teeth. Root resorption, dental ankylosis were not detected. No discoloration or radiographic evidence of loss of tooth vitality was noted. They concluded that the concept of distraction osteogenesis for rapid orthodontic tooth movement is promising and feasible.

Seher Sayin and Osman Bengi (2004) ⁶² evaluated the effects of rapid canine distalization through the distraction of periodontal ligament on the dentoalveolar tissues using semirigid, individual tooth-borne distractors. The study was carried out on 43 canine teeth in 18 patients who required first premolar extractions. The second premolar and first molar were used as anchor units. Orthodontic models, cephalometric and panoramic radiographs, and standard photographs of all the patients were taken before treatment and after the consolidation period. Periapical radiographs of the canines and anchor units were obtained once a week during the distalization period. The distractor was activated 0.25mm three times a day, and the canines were distalized efficiently on average of three weeks. They concluded that the maxillary canines were distalized an average of 5.76mm with 11.47° distal tipping. The maxillary first molar moved mesially 0.56mm and extruded 0.64mm. The maxillary incisors showed 1.44° of palatal tipping. The mean distal movement of the mandibular canines was 3.5mm with 7.16° distal tipping. Anchorage loss was not observed in the mandibular first molars.

DISTRACTION OSTEOGENESIS

Altuna, Walker, and Freeman et al (1995) ⁶ studied that maxilla could be successfully lengthened by surgical assisted rapid orthopedic movement, using the principles of distraction osteogenesis. Three experimental and three control adolescent cynomolgus primates were used in this study.

Anterior supraapical osteotomies of the maxilla with bilateral horizontal and interdental osteotomies were created between the first premolars and the canine; the anterior six tooth dental-osseo segment was completely mobilized in all animals. Beginning 1 week after surgery, a Glen-Ross screw oriented anteroposteriorly was opened a quarter turn every 2 days until the anterior segment was advanced by 4 mm in two animals and 6 mm in one animal. Animals were killed at 6, 8, and 12 weeks after completion of the maxillary orthopedic advancement. Bone deposition was assessed with computerized tomographic scans and histological examination. The computerized tomographic scans showed bone deposition in the osteotomy sites, which was confirmed by histologic observations. They concluded that this technique demonstrated repair by bone rather than soft connective tissue in the osteotomy sites, this procedure could be a useful method of treating midface retrusion.

Adi Rachmiel and Ian Jackson et al (1995)¹ studied to find a solution to the unsatisfactory postoperative maxillary relapse after major maxillary advancement or inferior repositioning of the maxilla. Midface advancement by gradual distraction was performed on young adult sheep over 21 days. Using an external device midface was advanced 36mm in the nasofrontal area and 43 mm in lateral aspect of the maxilla. The apparatus remained as external fixation device for 6 weeks after distraction for better ossification. They concluded that the new bone formed mature lamellar bone, which provided good support and a physical stop to the advanced segment. The small amount of relapse is attributed to soft tissue and muscular traction resulting from this huge advancement.

Michael Block and Deneen et al (1995)⁴⁷ studied the principles of distraction osteogenesis to advance the anterior maxilla of the dog using a

totally tooth-supported distraction device. After an anterior maxillary osteotomy, the distraction device was activated 0.5mm every 12 hours to advance the anterior segment 10 mm in 10 days. Serial tooth and radiographic measurement indicated that on the 10th day the average tooth advancement was 8.4mm \pm 1.5mm and the average skeletal advancement was 4.0mm \pm 1.5mm. After 6 weeks the average tooth advancement was 7.2 \pm 1.6mm and the average skeletal advancement was 3.0 \pm 1.3mm. After 3 months the tooth advancement was 6.2 \pm 1.5mm and at 6 months the tooth advancement was 5.0 \pm 1.1mm. The results suggested that a tooth-borne maxillary distraction device would result in significantly greater dental movement than skeletal movement.

Tavakoli and Walsh et al (1998) ³⁹ established the role of latency in mandibular distraction osteogenesis. Twenty-two growing sheep underwent bilateral mandibular corticotomies and attachment of an external lengthening device. Latent periods of 0, 4 and 7 days respectively were observed prior to beginning distraction. The distraction protocol consisted of a rate of 0.5mm twice daily for 20 days, followed by a consolidation phase of 20 days after which the sheep were killed. Histology, bone densitometry and 3 point mechanical testing were performed on the distracted mandible. It was found that a change in latency from 0 to 7 days does not alter histological features, biomechanical properties and bone density mass of the regeneration bone analyzed at 20 days post-distraction. They concluded that latency alone does not have a significant influence on the physical and mechanical properties of mandibular distracted bone and that the traditional practice of observing a latent interval in craniofacial osteodistraction may not be necessary.

Alvaro Figueroa and John Polley et al (1999) ⁷ reported a technique for maxillary distraction osteogenesis in cleft patient with severe maxillary

deficiency, with the use of a rigid external distraction (RED) device and an orthodontic appliance is required to deliver the traction force through the dentition to the maxillary bone. The study sample consisted of 14 patients with various cleft types and maxillary hypoplasia treated with the rigid external distraction technique. They concluded that maxillary distraction osteogenesis after complete osteotomy with the RED technique is a highly effective treatment modality to manage cleft-related maxillary hypoplasia.

Reha Kisnici, Stephen and Epker et al (1999) ⁵⁹ reported the first case of distraction osteogenesis to widen the mandible with the use of a tooth-borne appliance. In this report, a patient with Silver Russell syndrome and severe mandibular hypoplasia was treated by means of distraction osteogenesis of the midsymphysis to widen the mandible in concert with sagittal-ramus osteotomies to lengthen the mandible so that the severe crowding could be treated with nonextraction orthodontics. The authors concluded that this treatment created significantly increased arch length in the mandible, which was necessary to facilitate the patient's orthodontic treatment and this approach appears to have merits for consideration in similar patients with deficient lower jaws and moderate to severe arch-length discrepancies.

Steven smith, Rohit sachdeva and Jason cope et al (1999) ⁶⁵ evaluated the regenerate bone produced during osteodistraction of the dog mandible at three different consolidation times using quantitative computed tomography. Twelve skeletally mature male beagle dogs were equally separated into three experimental groups. Each dog underwent 10 mm of bilateral distraction osteogenesis to lengthen the mandible. After the distraction period, the bone was allowed to consolidate for 4, 6, or 8 weeks, at which time the animals were sacrificed and the mandibles harvested for computed tomographic imaging. They concluded that a significantly lower mean bone density of the

regenerate in the 4 week group when compared with either the 6 or 8 week group. There was no significant difference, however, in mean bone density between the 6 and 8week group.

Jason cope and Samchukov et al (1999) ³⁴ evaluated tooth movement through regenerate bone at an early time point during the consolidation phase after bilateral mandibular osteodistractor. Two beagle dogs underwent 10mm of bilateral mandibular lengthening via intraoral distraction osteogenesis between the fourth premolars and first molars. After 1 week of consolidation, retraction of the fourth premolars was initiated, immediately after completing premolar retraction, the dogs were sacrificed and the mandibles were analyzed radiographically, histologically, and by dental cast measurements. Initially, all 4 fourth premolars moved distally with 2 of the 4 touching the first molars at the time of sacrifice. They concluded that it is possible to move teeth through regenerate bone, and it appears that tooth movement can begin within weeks of starting the consolidation period.

Niederhagen, Braumann and Schmolke et al (1999) ⁵¹ studied whether a tooth-borne distraction device provided sufficient stability and guidance to the mandibular segment and whether there were any detrimental effects on the periodontium or neighboring teeth. Following bilateral osteotomy and after a latency period of 7 days, the distractor was activated 1mm per day till desired lengthening of the mandible was achieved. During the experiment, the callus and bone formation and potential dental and periodontal reactions were assessed radiologically and histologically. The radiological examination revealed sign of mature bone formation in the distraction gap, which corresponded well with the stability of the bone segment. No detrimental effects at the roots or

in the periodontium of the adjacent teeth were seen. Authors concluded that, lengthening or widening of the mandible using a tooth-borne distraction device seems stable without affecting the periodontium of the anchored teeth and it can be used as an alternative for bone-borne distraction.

Ulrich Meyer and Hans Peter et al (1999) ⁶⁸ investigated the biomechanical effects of mandibular lengthening in 32 rabbits on a cellular and histological level. The mandible was subjected to a corticotomy, held in a neutral position for 4 days, and then lengthened at various strain rates and frequencies for 10 days. Radiographic, histological and electron microscopic examinations showed strain-related bone regeneration. Application of physiologic strain rates (2000 microstrains) led to a bridging of the artificial fracture exhibiting woven ossification, whereas at 20,000 microstrains trabecular bone formation was demonstrated. In contrast, hyperphysiologic strain magnitudes (200,000 micorstrains or 300,000 microstrains) showed a fibrous tissue formation. Multiple strain applications (10 cycles/ day versus 1 cycle/day) increased the width of the distraction gap without changing the stage of bone regeneration. They concluded that gradual distraction of bone in physiologic magnitudes at higher frequencies seems to be desirable for a bony differentiation and may help to improve clinical applications.

William Bell and Samchukov et al (1999) ⁷⁰ analyzed the skeletal and dental positional changes on histomorphology of distraction osteogenesis and mucogingival periosteal tissues that occurred after simultaneous widening and bilateral lengthening of the mandible in baboons by a miniaturized intraoral bone-borne distraction appliance. The distracted gap and gingival tissues were analyzed clinically, histologically and radiographically. Result showed positional changes of the canine and incisor apices were proportional to the skeletal movement. Tipping of both

incisors toward the center of the distraction segment was noted. One incisor tooth showed rotation around the vertical axis during distraction and gradually returned during consolidation. Newly formed bone was parallel to the vector of distraction. Active histogenesis occurred in the stretched mucogingival periosteal tissues located in the distraction gaps.

Ulrich Meyer and Thomas Meyer et al (1999) ⁶⁹ studied the effect of magnitude and frequency of interfragmenary strain on the tissue response to distraction osteogenesis; defined daily strains were applied on mandibular osteotomies using an implanted mechanical distractor. Distraction was done by applying 2,000, 20,000, 200,000, or 300,000 microstrains once or 10 times per day respectively. Scanning and transmission electron microscopic examinations showed osteoblastic differentiation and early mineralization in samples distracted up to 20,000 microstrains, whereas higher strains magnitudes (200,000 or 300,000) led to formation of fibroblast-like cell surrounded by collagen fibrils and only slight mineralization. Multiple strain applications (10 cycles/days vs. 1 cycle/day) did not alter the histomorphometric indices or morphology significantly but increased the amount of newly formed bone. The authors suggested that the magnitude and not the frequency of mechanical loading control the differentiation of bone cells and the subsequent formation of bone tissue.

Eric Liou, Alvaro Figueroa and John Polley et al (2000) ¹⁹ hypothesized that a tooth can be moved into the fibrous new bone created by the distraction process at a rapid rate. Four mature beagle dogs were used and an edentulous space was created in 2 weeks by using a bone-borne intraoral distraction device on each side of the mandibular body between the third and fourth premolars. Calibrated elastic threads with 50 g of orthodontic force were applied to move the fourth premolar into the edentulous space for 5

weeks. On one side, the tooth was moved simultaneously with distraction; and on the opposite side, it was initiated immediately after the cessation of distraction. The fourth premolars were moved 1.2 mm per week. The authors indicated that the best time to initiate tooth movement was immediately after the end of distraction. With this approach, most of the periodontal support was preserved after orthodontic tooth movement. In contrast, moderate to severe alveolar bone loss was noted in the fourth premolars moved simultaneously with distraction.

Jason cope and Samchukov et al (2000) ³¹ evaluated the newly formed bone during the consolidation period of mandibular osteodistraction using quantitative histology. Seventeen skeletally mature male beagle dogs underwent 10mm of bilateral mandibular lengthening. After distraction, the regenerates were allowed to consolidate for 0, 2, 4, 6, or 8 weeks, at which time the animals were sacrificed and tissues harvested for standard histologic and histomorphometric analyses. Result showed mineralization began at the host bone margins by the end of distraction period, followed by a progressive increase in trabecular bone with a concomitant decrease in the amount of fibrous tissue. Between 4 to 6 weeks of consolidation, 3 types of relatively mature distraction regenerates were evident. The mineral apposition rate gradually increased from the end of distraction to the fourth week of consolidation, at which time it remained constant until sometime before the eight week, where it tapered off slightly as remodeling increased.

Marinho and Cesar Guerrero et al (2000) ⁴⁵ evaluated the effects of mandibular symphyseal distraction osteogenesis using a tooth-borne expansion device. The sample included 20 nonsyndromic patients between 13.5 years and 37.3 years of age. Predistraction (1.5 months before surgery), postdistraction (1 month after surgery), and long-term follow-up (1.3 year

after surgery) records included posteroanterior, lateral, and panoramic radiographs and models. Postdistraction radiographic evaluation showed that symphyseal distraction osteogenesis produced insignificant increases in the bicondylar, bigonion, and biantegonion widths; intermolar and, especially, intercanine widths increased significantly and a distraction gap was observed in the symphyseal region. The movement of teeth into the distraction regenerate and concomitant orthodontic treatment resolved dental crowding. Follow-up radiographs showed transverse skeletal stability of the distraction procedure. They concluded that mandibular symphyseal distraction osteogenesis increased mandibular arch width and corrected dental crowding, with a potential for disproportionate distraction patterns and proclination of the mandibular incisors.

Lindsey Douglas and Burton Douglas et al (2000) ⁴² determined the feasibility of using an intraoral, bone-borne and tooth borne-anchored appliance to distract baboon mandibles using the principles of distraction osteogenesis. Mandibular corticotomies were made in the ramus of the mandible unilaterally or bilaterally, and “pin-in-tube” (PIT) distraction appliance was applied. The appliance was activated an average of 0.86mm/day for an average of 12.4 days. The average mandibular lengthening measured between the markers was 7.9mm. Result showed that complications associated with use of extraoral distraction appliance like scaring of extraoral tissue, unwanted tooth movement, damage to vital structures and paresthesia were reduced using intraoral bone or tooth borne appliance. Authors concluded that intraoral, tooth-borne and bone-borne distraction appliance is an effective method to produce lengthening in the mandible by distraction osteogenesis.

Maria Troulis and Julie Glowacki et al (2000) ⁴⁴ defined the effects of latency and distraction rate on bone formation. For analysis of latency, mandibular osteotomies were distracted after 0 or 4 days at a rate of 1mm /day with 14 days fixation and for analysis of rate, osteotomies were distracted at 1mm, 2mm or 4mm per day to produce 12mm gap with 24 days fixation. Distracted bone was assessed by bimanual palpation to detect mobility and radiographs were used to estimate bone density. They concluded that anatomy of craniomaxillofacial distraction osteogenesis, especially its rich blood supply, is significantly different from that of long bones. Therefore, it may be possible that a shorter or even 0-day latency period would be feasible in the mandible. In the comparison of rates, stability was greatest in the group distracted at 1mm/day, which gave most consistent osteogenesis.

Hisako and Tsuyoshi et al (2000) ²⁸ studied the applicability of transport distraction osteogenesis with an internal appliance for reconstruction of the temporomandibular joint. Fifteen millimeters of the ascending ramus, including the condyle and intra-articular disc, was extirpated in 42 rabbits. After an osteotomy was performed from the anterior border of the coronoid process to the posterior border of the mandible, an internal distraction appliance was applied. The transport segment was advanced 0.9mm/day for 14 days after a 14-day healing period. The distracted gap was assessed radiographically and histologically. Result suggested that 8 weeks after completion of lengthening, the distraction gap between the transport segment and the pre-existing mandible was indistinguishable radiographically. New bone was also observed at the leading edge of the transport segment. The bone seemed to form from the surrounding periosteum and mature cortical bone was reconstructed. A collagenous-like

structure formed a cap over the leading edge of transport segment, which substituted for an articular disc. The authors concluded that new bone remodeled and resembled the condyle and bone transport technique is promising for the reconstruction of temporomandibular joint.

Peter Keßler, Wiltfang and Neukam (2000) ⁵⁵ hypothesized that continuous bone distraction exerts an osteogenic stimulus leading to more rapid primary bone formation without extensive callus formation using a hydraulic distractor. Histologically, results of continuous distraction showed lamination of the distracted bone area adjacent to the distraction site with longitudinally orientated columns of lamellar bone with early mineralization. Cartilage formation was not observed following continuous bone distraction. They concluded that the hydraulic bone distractor was effective; with mean pressure value level of 12 to 15x10⁵ was sufficient to move the piston constantly over 1.5mm within 24 hours to produce continuous bone formation.

Toshiyuki Hagiwara and Bell et al (2000) ⁶⁷ evaluated the effect of electrical stimulation on gradual mandibular lengthening by distraction osteogenesis. Twenty adult rabbits underwent mandibular osteotomies. After 3 days latency period, distraction device was activated at a rate of 0.7mm per day for 10 days. Direct current electrical stimulation of 10µA was applied to 10 rabbit and control group of 10 rabbit were not stimulated. The device was then stabilized for periods of 10, 20, 30 and 60 days in both groups. The distracted segments were assessed radiographically and histologically. They concluded that electrical stimulation during gradual distraction promotes new bone formation in the early retention period and may shorten the overall duration of lengthening.

Azita Tehranchi and Hossein Behnia et al (2001)¹¹ documented the changes in the facial symmetry of patients with severe hypoplastic mandibles treated with distraction osteogenesis and orthodontic therapy. Posteroanterior cephalograms were traced before distraction, 6 months after distraction, and at a later follow-up appointment. Displacement of the chin point (in millimeters) and the midpoint of the mandibular incisors, the piriform angle, the intergonial angle, the occlusal cant to the horizontal line (in degrees), the ratio of linear measurements (in millimeters) of the affected to the nonaffected side, were compared. The mean displacement of the chin point to the midline was 1.5 mm and that of the mandibular central incisors to the midvertical line was 1.38 mm. The results indicated improvement in all patients using distraction osteogenesis.

Claudia and Mommaerts et al (2001)¹⁵ investigated the hypothesis that by changing 2 parameter of standard protocol i.e., separating the pterygomaxillary disjunction and placement of the Transpalatal Distractor on the palate at the level of the first molars resulted in more parallel expansion of the maxillary segments. The transpalatal distractor (TPD) allows for maxillary expansion according to the concepts of distraction osteogenesis. Twenty consecutive patients were included in a prospective way, and their predistractor and postdistractor models were electronically analyzed. They concluded that pterygomaxillary disjunction changes the center of resistance locating it more posteriorly in relation to the site of force application, and the fulcrum was anteriorly situated which resulted in parallel expansion of maxillary segment.

Kai-Olaf Henkel and Lian Ma et al (2001)³⁷ evaluated the option of treating alveolar clefts by guided distraction osteogenesis instead of applying osteoplasty with autologous bone grafts from iliac crest, rib or fibula.

Treatment of each animal included creating bony defects measuring 2, 4, 8mm in the maxilla, anterior to the canine region and up to the nasal septum. In 15 of 30 animals, a new horizontal segment distractor was tested. The device was placed in site prior to creating an alveolar segment posterior to the defect. This segment was then transported gradually by distraction, thus crossing and closing the defect. At the end of the distraction and stabilization periods the newly formed bony tissue was examined. Results showed in five of six animals with a horizontal defect of 8mm, complete ossification of the defect had occurred following transport distraction osteogenesis. This technique was the applied to five patients successfully and it was shown that distraction osteogenesis is a valid alternative for treating alveolar clefts.

Jason cope and Samchukov et al (2001) ³² evaluated the mineralization dynamics of regenerated bone during distraction osteogenesis using plain film radiography and digital subtraction radiography. Thirteen skeletally mature male beagle dogs underwent 10mm of bilateral mandibular distraction osteogenesis, at that time the bone was allowed to consolidate for either 4, 6, or 8 weeks. They concluded that radiographic appearance of the regenerate is not limited to a simple three-zonal structure, but several different types of regenerate were evident during mineralization of the distraction gap. A classification system was presented based on the length, width, and density of the mineralizing regenerate, as well as the presence or absence of an interzone. It appears that important factors for determining regenerate stability are the presence or absence of an interzone, as well as the width of the regenerate relative to the host bone segments. Finally, in case where interzone is present, subtraction radiography may provide a means of evaluating the level of mineralization with the interzone as well as

the dynamics of mineralization over the course of distraction and consolidation.

Al Ruhaimi et al (2001)³ evaluated bone distracted in rabbit mandible at different intervals and different daily rates of distraction histologically with the goal of attaining a universally accepted distraction protocol. Osteogenesis was investigated in mandibles distracted at different rates using a custom-made submerged distractor. The animals were divided into four groups: Group 1 was distracted 0.5 mm twice a day, Group 2 was distracted 1.0 mm once a day, Group 3 was distracted 1.0 mm twice a day and Group 4 was distracted 2.0 mm once a day. He concluded that distraction rate of 1.0mm per day produced the best osteogenesis among the tested rates. There was no great difference in osteogenesis between 1.0 mm once a day and 0.5 mm twice a day. However, 0.5 mm distraction may result in immature bone healing, 1.0 mm twice daily resulted in incomplete osteogenesis, while distraction of 2.0mm once a day resulted in fibrous union.

Wiltfang, Keßler and Merten et al (2001)⁷¹ recorded pressure values in continuous and intermittent distraction osteogenesis, and compared histological findings using light and electron microscopes followed by ultrasonography. Continuous and intermittent bone distraction was done using a microhydraulic cylinder in six minipigs. After seven-day interval, continuous or intermittent distraction of 1.5mm/day was established for 10 days. Immediately after active distraction animals were sacrificed. The mandible was then removed en bloc and the distracted bone was examined histologically. Intermittent distraction forces of up to 2500 kPa were necessary to move the cylinders' piston. The authors concluded that specific histological structure of the varying zones in the distraction gap was similar

after continuous and intermittent distraction; bone healing was accelerated after continuous distraction as shown by ultrasonography and scanning electron microscopy.

Ayoub and Richardson et al (2001) ¹⁰ invented a distraction device that can be placed intraorally and provide autodistraction. The device consists of two units: an implantable component that is applied directly on the bone, an external component that is distant from the surgical site. The external component is mounted on a standard battery-driven portable syringe driver or infusion pump. A fine definable non-compressible tube connects the two. The compression of the bellows in the external component causes fluid to be forced through the connecting tube into the distraction component. The combination of sealed system and incompressible fluid expands the bellows of distraction component which gradually separates the bone segments. Authors concluded that this device has the advantage over motor-driven automatic devices:

1. Less bulky
2. Readily adjustable without surgical intervention
3. Activation component is away from the surgical site
4. Separation of the bone segment at the distraction site can be monitored through the external component, which eliminates the necessity of taking radiographs during the course of distraction.

The design of the system allows changes to be made to both the rate of distraction and the frequency as both these factors are controlled by the external drive system.

Stanley Braun and Alexandre et al (2002) ⁶⁴ determined the true nature of condylar displacements associated with mandibular symphyseal distraction osteogenesis. Earlier investigators have assumed that each mandibular half

rotated about a point near the center of each condyle as viewed on a submental radiograph. Study included 12- patient sample, 10 with tooth-borne symphyseal distraction and 2 with bone-borne symphyseal distraction. They concluded that that each condyle was laterally displaced in direct relationship to the amount of symphyseal distraction. The rigidity of the distraction appliances and their attachments and the inability of the soft tissues and muscular attachments to cause the mandible to undergo compound bending require this to be the case. Temporomandibular joints appear to be able to accommodate the lateral displacements because symptoms were not introduced, or, if present before therapy, distraction did not exacerbate them.

Norimichi Nakamoto and Hiroshi Nagasaka et al (2002) ⁵² verified the influence of tooth movement on tooth roots and periodontal tissues when teeth were moved into mature, well organized, and mineralized bone created after distraction osteogenesis compared with immature, fibrous, and less-mineralized bone. Six 15-month-old male beagles dogs underwent 10mm of bilateral mandibular distraction osteogenesis. After 2-week (group 1) and 12-week (group 2) consolidation, third premolars were moved into the regenerate bone with 100grams of orthodontic force for 12 weeks. Simultaneously, second premolars were also moved distally as controls. Result showed that in group 1 considerable root resorption extending into the dentin and the thickness of the dentin became approximately half that of the compression side. In-group 2, root resorption on the compression side reached the dentin, but the root resorption was less than in group 1. The authors concluded that heavy and early orthodontic tooth movements are not recommended when teeth are moved through regenerated bone created by distraction osteogenesis.

Mary Trahar and Sheffield et al (2003) ⁴⁶ in a pilot study evaluated cephalometrically the efficacy of an intraoral distraction osteogenesis device in treating patients with unilateral mandibular distraction. Posteroanterior and 45° lateral oblique cephalograms were measured, and changes in maxillary width and height, occlusal height, ramus height, mandibular length, and chin position were quantified. Measurements were taken preoperatively and postoperatively at 7-time point over 2 years. The cephalometric data suggests that the intraoral distractor is as capable of lengthening hypoplastic mandibles as the initial extraoral appliances. The bone lengthening appears stable, with the distracted side of the mandible maintaining a growth similar to normal side. Immediately after distraction, transient improvements were noted in maxillary height, ramal height and maxillary width. All patients demonstrated an immediate improvement in chin position toward the skeletal midline.

Gero Kinzinger and Siegfried et al (2003) ²⁴ tested whether, after a shortened consolidation phase, orthodontic fine adjustment of the tooth-supporting osteotomy segment could be achieved by applying the “floating bone concept”. They performed a segmental osteotomy with vertical callus distraction of the ankylosed tooth, using the floating bone concept, and at the same time, 3-dimensional alignment of the tooth-supporting segment using mutliband apparatus and appropriate biomechanics followed by a rigid continuous archwire induces relatively fast stabilization of the tooth-supporting segment for immobilization of the callus. They concluded that floating bone concept achieved 3 dimensional alignment of ankylosed tooth, allowing tooth movement into the therapeutically desired position.

Tae and Gong et al (2003) ³⁸ reported a case of dentoalveolar distraction in a repaired unilateral alveolar cleft patient using a tooth-borne distractor.

Horizontal osteotomy was made 2mm above the canine and first premolar apex and vertical osteotomy was made mesial to canine and distal to first premolar to close the cleft by a forward transport of bone using a segment from canine and premolar teeth. A tooth borne device was placed on canine and first and the distractor was activated until the segment mesialized and reduced the alveolar cleft. Result showed canine tipping forward and the premolar showed mesial in rotation. After a consolidation period of two weeks, the first molar was moved into the newly created bone-regenerated area. They concluded transport distraction osteogenesis would reduce or eliminate the need for a secondary bone graft to the cleft alveolus in cleft patients and help prevent dentoalveolar defects by approximating the native alveolar bone and gingiva.

Dolanmaz and Ali Ihya et al (2003) ¹⁷ evaluated the usage of dento-osseous transport distraction osteogenesis in the treatment of cleft alveolus. The procedure was carried out on eight patients, 3 with bilateral alveolar clefts and two with unilateral alveolar clefts. A custom made tooth-borne distractor was used. Result suggests that the average amount of distraction was eight mm (range 5-11.5mm); average amount of distal movement of the anchorage teeth was 0.8mm(range, 0-2mm), average amount of inclination changes of the transport segments and anchorage teeth was 7.6° (range, 2-17.5°) and 3.3° (range, 0-9°) respectively. They concluded that this method form repairing small or large alveolar cleft is a simple, cost-effective, and useful treatment option.

Faruk Ayhan and Hasan et al (2004) ²² evaluated the biomechanical effects of mandibular midline distraction osteogenesis on the mandibular complex by using a 3 dimensional finite element model, whose construction was based on computer tomography scans of the mandible of 22-year old

man. The distraction was performed on the middle intersection point of the vertical and horizontal planes on the mandibular symphysis. The result indicated the mandible was separated almost in parallel manner superioranteriorly. Anteroposterior evaluation demonstrated that the greatest widening was achieved at the symphyseal region, and the widening gradually decreased from anterior to posterior and this result in minimal disturbance of the condyle region. The authors suggested that these findings stress the importance of the design and location of the distractor in treating transversal deficiencies. A tooth-borne or bone-borne distractor placed on the mandibular anterior surface slightly above apex of the mandibular incisors, would cause parallel widening of the mandible.

Osman Bengi and Gurtun et al (2004) ⁵³ defined a technique of bone regeneration and osteosynthesis of native preexisting bone. The technique offers a promising treatment alternative for patient with maxillary hypoplasia and a retrognathic mandible. In this case report, an 18.2-year-old girl was treated by pre-maxillary advancement using an individual tooth-borne distraction device. The surgical operation consisted of classical segmental maxillary osteotomy and the distractor was placed in the mouth after the surgical procedure. After seven days latency period the device was activated 0.5mm every 12 hours. A result showed that the anterior crossbite was eliminated in one week and the profile of the patient improved. Treatment was completed using fixed orthodontic appliances.

PALATAL RUGAE AND MARKERS

Almeida et al (1995) ⁵ demonstrated that the medial points on the palatal rugae were stable during normal growth as well as treatment with headgear or functional appliance.

Bailey et al (1996) ¹² conducted a study with pre-treatment and post-treatment maxillary dental casts of 57 patients and concluded that the medial and lateral points of the third palatal rugae are stable landmarks for the construction of reference planes in the evaluation of tooth movement in a transverse, linear and anteroposterior direction, whether patients are treated with or without extraction.

Gulati et al (1998) ²⁶ made photocopies of pre-retraction and post-extraction casts on the same machine with 1 to 1 duplication. He dropped perpendiculars from the points on the maxillary permanent molars to the incisive papilla perpendicular reference plane and thus measured anteroposterior movement of maxillary molars.

Keles et al (2000) ² used wire markers for lateral cephalometric analysis of tooth movement and determining the amount of tipping of maxillary molars during distalization with the intraoral bodily molar distalization.

Hoggan and Sadowsky et al (2001) ¹³ in their study on 33 patients treated with first premolar extraction concluded that the rugae landmarks could be used as reliably as cephalometric superimposition to assess anteroposterior molar movements. They suggested that the medial end of the third palatal rugae is a suitable reference point for the assessment of molar and incisor movement.

SUMMARY AND CONCLUSION

The study was done to evaluate a new method of rapid canine retraction using the principles of distraction osteogenesis. Three patients' two boys and one girl, mean ages 14 years (range 13-15) were selected to participate in this study.

The individual canine distractor used in this study was a custom made, semirigid, intraoral, tooth-borne device. Orientation of the distraction device was parallel to the maxillary occlusal plane and was kept as near as possible to the center of resistance of maxillary canine. Distraction vector orientation was horizontal. Since the distraction appliance was unilateral, a 360° activation of the screw with the screw wrench produced 0.4mm of distal movement of canine tooth.

The clinical procedure had a surgical phase and distraction phase. The surgical procedure involved both extractions of the maxillary first premolars and preparation of the alveolar bone around the canine root to facilitate dentoalveolar distraction (Transport bone disc). The **dentoalveolus** was designed as a bone transport segment for posterior movement. Distraction was initiated immediately after the surgery. Advancement at the rate of 0.4mm was performed twice a day until each canine tooth was distracted into the desired position. Rapid canine retraction was achieved with this new technique. After 12 weeks of consolidation period, the distraction devices were removed and the study was continued to assess various parameters.

Distal movement of canine, mesial movements of molar, canine and molar rotations was measured using photographic copies of study models. Tipping of canine was assessed using lateral cephalograms with radiopaque markers.

The results indicated that maximum amount of canine retraction was achieved with negligible amount of molar anchorage loss. Canine and molar rotations were insignificant. Lateral cephalograms with radiopaque marker revealed no significant degree of canine tipping indicating bodily movement of canine.

It is clear from this study that rapid canine retraction can provide faster and maximum canine movement with minimal undesirable changes. The long-term effects on root resorption, pulp vitality, periodontal tissue, and possible root ankylosis of the canine should be closely monitored.

Currently, the canine distractors are bulky, unidirectional and not available in the market. They need to be refined, developed, and oriented with fixed appliance in the future. The concept of distraction osteogenesis for rapid orthodontic tooth movement is thought to be promising and feasible for clinical practice.

The study conclusively proves that canine can be rapidly distalized by employing the principle of distraction osteogenesis and without anchorage loss or other unfavorable changes in the dentition. Future study should attempt to improve the appliance design and a large sample should be used and the effects of the procedure should be observed for a longer period.

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