# Clinical and histological evaluation of suture expansion by using orthodontic microimplant as bony anchorage

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**Title** Clinical and histological evaluation of suture expansion by using orthodontic microimplant as bony anchorage

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## ABSTRACT

The objective of this study was to investigate a morphological pattern and intersuture tissue changes of the expanded interfrontal suture of rabbits by using a custommade distraction device combined with orthodontic microimplants as a bony anchorage. Eighteen 30-day old New Zealand White rabbits were divided into 4 experiment groups (A, B, C, D), 4 rabbits per group, and 2 rabbits were leftover for the sham group. The interfrontal suture was expanded by using a modified distraction device combined with 2 orthodontic microimplants as a bony anchorage on both sides of the suture and activated 0.4 mm. per time, twice daily for 7 consecutive days. The rabbit were sacrificed at 10 days, for group A, 2 weeks for group B, 4 weeks for group C and 8 weeks after completing activation for group D and the sham group. The cranial vault including the distraction interfrontal suture was removed en bloc. The results showed that regenerated tissue in the distraction gap had changed from a yellowish-red color and a soft fibrous-like structure in group A, to a bony hard consistency tissue as in the sham group in group D. The radiopacity of the expanded gap increased gradually in group A and was almost the same level as the sham group in group D. In addition, the histological finding of the re-established interfrontal suture structures in group D was quite similar to that found in the sham group. In conclusion, the custom-made distraction device, using orthodontic micro-implants as a bony anchorage, could be successfully used for interfrontal suture expansion without an osteotomy in rabbits, and no any complications were found. The clinical application should be the next step to be studied and evaluated.

**Key words**: cranial suture expansion; distraction osteogenesis; interfrontal suture; micro-implant

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Wipapun Ritthagol

# Content

## Introduction

Current treatment modalities for children with congenital craniofacial deformities involve a variety of invasive surgical treatment procedures throughout the growth and development period. These major invasive surgical operations usually resulted in marked postoperative morbidity and discomfort. In addition, although early surgical interventions have been successfully performed to correct current and impending problems, relapse and restricted growth frequently necessitates additional procedures at a later stage.

Apart from the treatment of craniofacial deformities by major surgery to correct malformation of the skull, external force has been used to correct the deformity gradually during the child's development. The procedure can be traced back to the modification of the head shape in some cultures and present clinically rapid palatal expansion. This approach has potential benefit by allowing incremental movement of the bone segment and subsequent soft tissue changes to occur more gradually. Upon this basis, more extensive movements could be attained without severe complication and relapse. In addition, limitations in autogenous bone for grafting or other graft sources including the rigid fixation that results in cranial growth retardation, could be avoided. Two basic approaches were conducted using externally directed mechanical forces to change the morphology (size and shape) of the skeleton including expansion of open sutures: the rapid palatal expansion procedure and the distraction of controlled osteotomies or corticotomies.

### Distraction osteogenesis

Distraction osteogenesis is a method of producing unlimited quantities of living bone directly from a special osteotomy by controlled mechanical distraction. The new bone spontaneously bridges the gap and rapidly remodels to a normal macrostructure local bone.[1-3] Distraction osteogenesis is also called similar to Callostasis generating new bone by stretching the callus. As in a fracture, this concept of bone lengthening was first described by Codivilla in 1905[4], who used it to elongate a femur by repeated pulling forces. Other investigators also applied this technique but it remained undeveloped because of associated complications such as nonunion, nerve damage, local edema, skin necrosis, and pin track infection.[5;6] However, the technique of bone lengthening by gradual distraction was further developed and refined by Russian orthopeadic surgeon G.A. Ilizarov in 1952.[1] Since distraction osteogenesis used local host tissue to regenerate new bone, it offers many potential advantages over bone grafting.

Sources of autograft are limited and may leave local morbidity at the donor site. Allografts may transmit unknown antigens, bacteria or even viruses. As dead foreign bodies, allografts may not be desirable in infected wound. The use of distraction osteogenesis in the craniofacial skeleton was first reported by Snyder et al.[7] using monofocal distraction to lengthen canine mandible. Successful clinical bone lengthening in the craniofacial surgery was first described by McCarthy et al. in 1992.[8] Using extraoral distraction devices, McCarthy lengthened the congenital hypoplastic mandible in four children with Nager's syndrome. The result was satisfied with new bone formation and no relapse was found. Since then several clinical reports with a variety of devices and techniques are available to lengthen segments or entire maxillary or mandibular arches[9-12]. Although the application of the Illizarov technique to maxillofacial skeleton showed promise, its use has not been widespread. Extraoral appliances have been effective in clinical cases, but their use has been hampered by many complications.[8;13] These included skin or bone necrosis, pin track infection, scarring, facial nerve and inferior alveolar nerve injury and poor predictability.[8;14] Michieli and Miotti have addressed these concerns by the use of the specially fabricated intraoral tooth-borne appliance to provide the necessary distraction The development of intraoral appliances occurred in several centers and authorities as reported by Guerrero[15], McCarthy et al[16], Chin and Toth[9] and Diner et al[17;18] Potential benefits of internal devices included 1) elimination of skin scars caused by translation of transcutaneous fixation pins, 2) improved patient compliance during the fixation or consolidation phase because there is no external component, and 3) improved stability of the attachment of the device to bone. The following cases report demonstrate the use of intraoral distraction devices to correct a variety of maxillofacial skeletal deformities in three patients. This included mandibular ramus lengthening in hemifacial microsomia patient, maxillary distraction in cleft lip and palate patient and interdental distraction of posterior maxilla in benign odontogenic bone tumor after tumor resection.

Methods of orthodontic maxillary expansion

For maxillary constriction, result in transverse discrepancy of dental arch relationship, a wide variety of modalities for orthodontic treatment in transverse dimension reported in the literature includes banded, bonded, and removable appliances, as well as appliances not typically used for expansion, such as headgear and functional appliances. The methods used for corrected

are slow orthodontic expansion (SOE), rapid maxillary expansion (RPE), surgically assisted rapid palatal expansion (SA-RPE) or a two-segmented Le Fort I-type osteotomy with expansion.[19] Traditionally, the devices used to correct transverse maxillary discrepancy are tooth borne appliance or tooth-tissue borne appliances i.e. Hyrax appliances, Hass appliance or other jack screw appliances, for slow orthodontic expansion and rapid maxillary expansion are transferred forced through teeth then resulted in activation on circummaxillary sutures for increasing maxillary width. Many study shown several complications occur to teeth attach to devices such as periodontal membrane compression, buccal root resorption[20] fenestration of buccal cortex, buccal tipping of teeth, extrusion, root resorption, and fenestration of the alveolar process which lead to periodontal side effects.[21] Due to Newton's third law, for every action there is an equal and opposite reaction, there are limitations in our ability to completely control all aspects of tooth movement.

In contrast, with bone-borne distractors applied at a higher level in the palatal vault, most of the maxillary expansion is orthopedic and at a more mechanically desired level[22]. In addition the forces are directly on the bone and no tooth tipping and other unwelcome side effects are to be expected. The commercially available bone-borne distractors like the Transpalatal Distractor (TPD™)[19] have to be fixed with screws on the palatal bone and have proven to be useful in acquired deformation patients. The MDO-R device (Orthognathics Ltd.) has no screw fixation; however it has a minimal width of 1.5 cm. In congenital patients with extreme narrow maxillas these devices seem to be impractible due to difficulties with screw fixation and the devices are often too large to be placed.

Temporary Anchorage devices

Temporary anchorage devices (TADs) are temporarily fixed to bone for the purpose of enhancing orthodontic anchorage either by supporting the teeth of the reactive unit or by obviating the need for the reactive unit altogether, and which is subsequently removed after used. They can be located transosteally, superiosteally, or endosteally; and they can be fixed to bone either mechanically (cortical stabilized) or biomechanically (osteointegrated). The first clinical report in the literature of the use of TADs appeared in 1983 when Creekmore and Eklund[23,24] used vitalium bone screw to treat a patient with a deep impinging overbite. Even though the successful application of TADs, this technique did not gain immediate acceptance because lack of wide spread acceptance of surgical procedures, unaccepted field of implant dentistry, the lack of

scientific data on the use of implantable materials, and fear of complications. Instead, traditional anchorage mechanics remained the principle treatment modality for managing orthodontic problems.[23]

The biocompatible TADs are either 1) a modification of a dental implant, or 2) a surgical fixation method. For example, a palatal implant is a miniaturized dental implant placed in the palate with the intention of osseointegration and subsequent use for orthodontic anchorage. On the other hand, a miniscrew is a fixation device placed in many locations for anchorage control without the intention of osseointegration but only for mechanical stability.[24]

The micro-implant generally is made of titanium alloy. It has four components: head, neck, platform and screw body (Figure 3). The head has access to hold an orthodontic archwire, ligature wire or elastic chain. The neck area (isthmus) between head and platform may have a round perforation to hold additional ligatures or archwires. The smooth platform surface enhances peri-implant wound healing and prevents the screw head from protruding into the soft tissue. As the screw body has a self-tapping design or self-drilling design.[25] For self-drill method,the microimplant is driven into the tunnel of bone formed by drilling, making it tap during implant driving. This method is used when using small diameter microimplants. The other, self-tapping method, the micro-implant is driven directly into bone without drilling. This method can be use when using larger diameter (more than 1.5 mm) microimplants.[26]

Stability of orthodontic micro-implant

Orthodontic micro-implant anchors such as titanium screws have been used for absolute anchorage during edgewise treatment. Miyawaki et al reporting the stability of implant anchors placed in the posterior region, human studies. The success rates and factors associated with the stability of titanium screws were examined in relation to clinical characteristics[27]. The 1-year success rate of screws with 1.0-mm diameter was significantly less than that of other screws with 1.5-mm or 2.3-mm diameter or than that miniplates. Flap surgery was associated with the patient's discomfort. A high mandibular plane angle and inflammation of peri-implant tissue after implantation were risk factors for mobility of screws. But they did not detect a significant association between the success rate and the following variables: screw length, kind of placement surgery, immediate loading, location of implantation, age, gender, crowding of teeth, anteroposterior jaw base relationship, controlled periodontitis, and temporomandibular disorder symptoms[27].

Liou et al studied about stationary of microscrews, they concluded that miniscrews are a stable anchorage but do not remain absolutely stationary throughout orthodontic loading. They might move according to the orthodontic loading in some patients.[28]

Deguchi et al studied about bone-implant interface of small titanium screws as an orthodontic anchorage for establishing an adequate healing period in dog. Overall, successful rigid osseous fixation and the "three-week unloaded" healing group were: increased labeling incidence, higher woven-to-lamellar-bone ratio, and increased osseous contact. All of the loaded implants remained integrated. Mandibular implants had significantly higher bone-implant contact than maxillary implants. The data indicated that small titanium screws were also able to function as rigid osseous anchorage against orthodontic load for 3 months with a minimal (under 3 weeks) healing period.[29]

The present study investigated the ability to use a custom-made distraction device modified from a microimplant and orthodontic expansion screw, to expand the growing craniofacial suture in a rabbit model. The device was fixed to the craniofacial bone by microimplant to provide stable skeletal points as the bony anchorage for direct application of external forces to alter growth and anatomic form of the suture. The objectives of the present study were to assess the efficacy of the microimplant as the bony anchorage for the cranial suture expansion, developing an efficient animal model for cranial suture distraction osteogenesis, and evaluate the effect of distraction osteogenesis without an osteotomy across the interfrontal suture in growing rabbits both in a morphological pattern and in inter-suture tissue changes.

## Materials and Methods

Eighteen, 30-day old, 1-1.5 kilogram inbred male New Zealand white rabbits used for the experimental model. They were divided into 4 experiment groups (A,B,C,D), with 4 rabbits per group and 2 rabbits for the sham group. The custom-made distraction device was composed of two components: the abutments and the expansion screw part. The 1.6 mm diameter, 10 mm long self-tapping titanium microimplant (Absoanchor, Dentos Inc, Korea) was used as the bony abutment anchorage. The expansion screw part was fabricated from an acrylic component embedded with a 10mm expansion screw (Dentarum Co., Ltd). The two components were connected by zinc phosphate cement. (Fig. 1a, b)

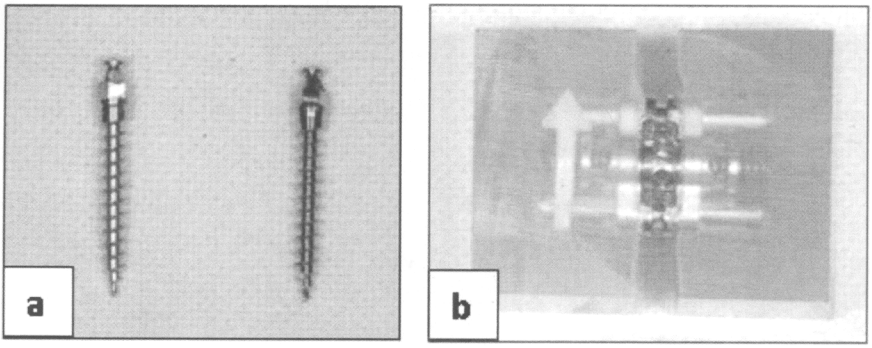


**Fig 1** a: the titanium microimplant. b: the orthodontic expansion screw embedded in acrylic resin.

The rabbit was sedated with 25 mg/kg Ketamine HCl and 5 mg/kg Diazepam IM 15 minutes prior to the operation. Then 5mg/kg of Thiopental was injected intravenously followed by 2mg/kg of titration and repeated every 15 minutes (maximum dose should not exceed 30 mg/kg) until the animal was unconscious[4] . Penicillin G sodium was given before the beginning of the procedure. The rabbit was placed in the prone position and hair was shaved from the frontal to the occipital region and painted with betadine solution. The local anesthetic agent, 2% Lidocaine with 1:100,000 epinephrine 1.8 ml, was injected subcutaneously. The midline sagittal scalp incision was carried out through skin and subcutaneous tissue. The pericranium tissue was elevated to identify the interfrontal and adjacent sutures. The soft acrylic template was fabricated for reproducible locating of the pilot drill hole 5 mm each side of the interfrontal suture. The microimplant was inserted into the prepared hole by the self tapping method. The friction of the engagement was controlled within the range of 5-10 cm by a torque gauge screwdriver (Absoanchor, Dentos Inc, Korea). Two small round bone markers corresponding to the implant site was created and filled up with radiopaque gutta percha. (Fig 2)

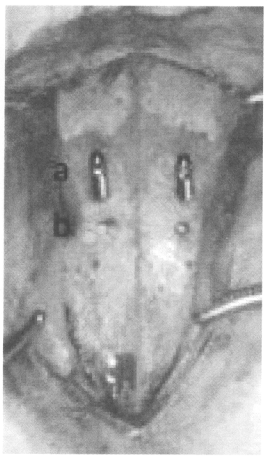


**Fig 2**: Demonstration location of microimplants (a) and gutta percha bone markers (b) on both sides of the interfrontal suture.

The following distances including the width between the two microimplants, at the bone level, top level and the inter-bone marker distance were recorded by a digital veneer caliper (Digimatic Caliper, Mitutoyo, Japan). Similar parameters were repeatedly recorded again at the time of sacrifice. The surgical wound was cleaned with normal saline and closed in layers with resorbable suture material. Finally, the expansion appliance was placed on inserted microimplants and secured with zinc phosphate cement. (Fig 3) 10 mg/kg Pethidine was injected intramuscularly for pain control and 100,000 units/kg/day of Penicillin G Sodium was continued for 5 days postoperatively.

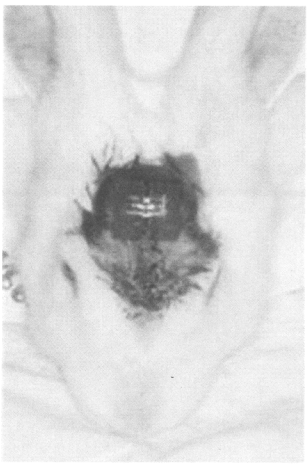

**Fig 3**: The expansion device was connected to the microimplants by using zinc phosphate cement.

The activation began 3 days after the operation in all groups except the sham group, with 0.4 mm/time, twice daily, for 7 consecutive days. The activation was able to be performed with gentle restraint of the animal without causing any discomfort. The experiment rabbits in each group were sacrificed (n=4) by intraperitoneal overdose of Thiopental Sodium (100-150 mg/kg). (Fig 4) according to the following group: Group A: upon completion of distraction, Group B: at 2 weeks, Group C: at 4 weeks and Group D along with the sham group: at 8 weeks after completion of distraction.

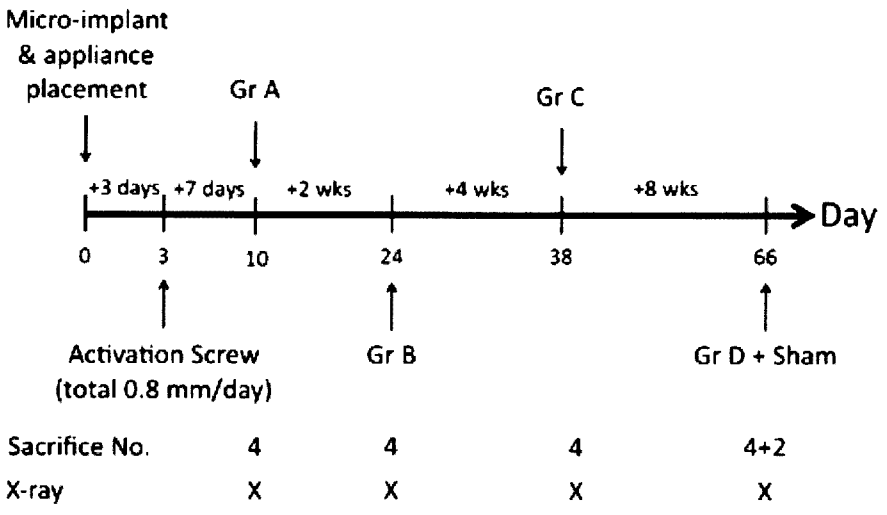


Fig 4: Demonstrated scheme of the experiment.

The cranial vault including the distraction interfrontal suture was removed en bloc. After the attached soft tissue was removed and cleaned, the gross morphological appearance was observed and recorded. The dorso-ventral radiographs were taken with occlusal film (Kodak Ultra-speed DF-49, Carestream Health Inc. USA),10 mA, 50 KVP, 0.34 sec, using the same dental radiographic machine (Gendex, Gendex Co., USA). The aluminium step wedge was attached to each film in order to calibrate the radiodensity. In addition, the custom made film holder was used so that the same position and distance was able to reproduce. All radiographs were processed by an automatic film processor (Dent X 9000, Dent X/Logetronics GmbH, Germany). All radiographs were scanned and transferred into a personal computer by an imaging densitometer (Bio-rad GS700, GS-700, GMI Inc, USA) at the resolution of 2672x3558 pixels. The radiodensity in the expanded gap of all experimental groups were quantitatively calculated using image processing and analysis software (Leica Imaging System Ltd, England). After completion of the radiographic analysis the specimens were processed for the histologic study. Rinsing in a 10% solution of formalin fixation, specimens were placed into a decalcifying solution containing ethylene diamine tetraacetic acid and were then embedded in paraffin. A 5-microns thickness was cut and stained with Hematoxylin-Eosin. A light microscopic examination (Nikon Eclipse E22, Nikon Instrument Inc., USA) was performed and the details of the tissue in the area around the suture was assessed and recorded.

## Results

The animals tolerated the surgical operation well and the distraction procedure was performed without any complication or neurological morbidity encountered. The surgical wound healed with no infection especially in the peri-implant region. The distraction could be performed two times daily under gentle restraint without anesthesia. Seven consecutive days of distraction were successfully achieved in all animal models without failure or dislodging of the distraction devices. The stability of all microimplants was observed during the distraction period throughout the sacrifice times in all groups. The distance of the suture expansion gain according to the bone markers in each group was 3.72 mm ± 0.63 (group A), 4.35 mm ±0.36 (group B), 4.45 mm ±0.35 (group C) and 4.29 mm ±1.49 (group D) respectively, when compared to the expected distance of 5.6 mm provided by the distraction device. The obtained expanded gap was significantly more than the normal physiological growth of the suture in the sham group (0.48 mm ±0.09 mm.). It was noted that none of the distraction devices became unstable nor any microimplants dislodged throughout the period of the experiment in all groups. In addition, no significant difference of the expanded distance between the bone level and top level of the microimplant was found. It can be stated that microimplants used in the present study could resist distraction force from the surrounding soft tissue and suture structure against the expanding vector without bending outward during the distraction period. (Table 1)

**Table 1**: Demonstrated the distance gained from the suture expanded gap in each group of the experiment.

| Group | Gutta percha bone marker (mm) | | Micro-implant bone level (mm) | | Micro-implant top level (mm) | |
|---|---|---|---|---|---|---|
| | Mean | Mean | Mean | SD | Mean | SD |
| A | 3.72 | 0.63 | 4.42 | 0.94 | 6.03 | 0.14 |
| B | 4.35 | 0.36 | 5.21 | 0.50 | 5.37 | 0.13 |
| C | 4.45 | 0.35 | 5.35 | 0.44 | 5.44 | 0.40 |
| D | 4.29 | 1.48 | 5.20 | 0.56 | 5.09 | 0.31 |
| Sham | 0.48 | 0.09 | 0.57 | 0.07 | 0.35 | 0.17 |

Gross morphological evaluation

The cranial vault including the interfrontal suture was removed and all the attached soft tissue was cleaned. The expanded suture was observed and recorded.

Group A: sacrifice of rabbits at completion of distraction (Fig 5a).The interfrontal suture was expanded in an elliptical shape pattern. The distraction suture was also extended to the adjacent mid-sagittal suture through the occipital and nasal bone. The inter-sutural tissue had a yellowish-red color with fibrous connective tissue-like consistency and an irregular surface. Due to this appearance, the intersutural tissue was easily distinguished from the native sutural bone.

Group B: sacrifice of rabbits 2 weeks after complete distraction (Fig 5b). The expanded interfrontal suture still could be noticed and discriminated from the native sutural bone. The regenerated soft tissue in the intersutural gap changed to a light yellow color. The surface appearance was smooth and the consistency was rather firm when compared to the first group. The parallel streaks of tissue that lay perpendicularly across the suture gap were also observed.

Group C: sacrifice of rabbits 4 weeks after complete distraction (Fig 5c). The clinical feature of the soft tissue band in the expanded gap appeared smaller than the in group B. The regenerated tissue had coloration and a firm to hard consistency similar to callus formation in a

bony healing process. The surface texture and the border of the regenerated tissue in the expanded gap looked more difficult to distinguish from the adjacent normal bone.

Group D: sacrifice of rabbits 8 weeks after complete distraction (Fig 5d). The regenerated tissue in the expanded gap was reduced in size and changed from a soft fibrous-like structure to a bony hard consistency tissue similar to the normal interfrontal suture of the sham group (Fig 5e). The anatomical normal cranial suture appeared to have re-established in the mid line.

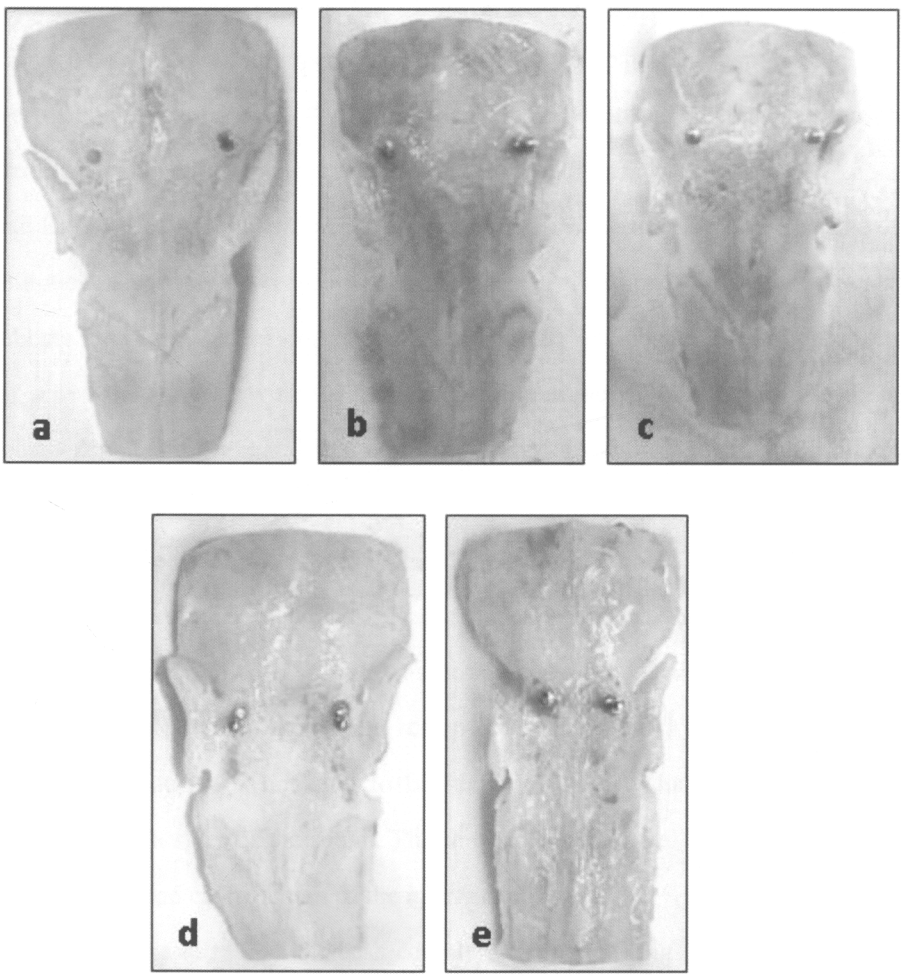


**Fig 5**. Gross morphological features of the calvarium including the distracted interfrontal suture at each time interval. a: at completion of distraction. b, c and d : 2,4, and 8 weeks after complete distraction respectively and e: the sham.

Radiographic evaluation

After gross morphological evaluation the cranial vault specimens were analyzed by radiographic means. The radiographic examination was performed using dental occlusal film of the various intervals regarding the experimental group.

Group A: sacrifice of rabbits at completion of distraction (Fig 6a). The radiographic finding demonstrated a well-defined radiolucent elliptical shape of the expanded interfrontal suture along the mid-sagittal direction. The distracted suture even extended through the adjacent suture of both nasal and parietal bones. The separated original suture bone had clear defined margins. Although the majority of the expanded gap was occupied by the radiolucent area, small delicate radiopaque streaks running perpendicular across the expanded gap parallel to the distraction vector could be observed. The small round radiolucent and radiopaque area of the implant insertion and gutta percha bone markers were also identified.

Group B: sacrifice of rabbits 2 weeks after complete distraction (Fig 6b). The size of the radiolucent elliptical shape gap decreased and had less well-defined margins. Numerous parallel small and delicate radiopaque streaks originated from both the native suture host bones running perpendicular across the suture leaving the radiolucent zone in the midline. It was also observed that the previous expanded mid-sagittal suture of nasal and parietal bones significantly filled with radiopaque tissue.

Group C: sacrifice of rabbits 4 weeks after complete distraction (Fig 6c). The radiopacity in the distraction gap continued to increase simultaneously with the decrease in size of the radiolucent expanded area. The calcification was nearly complete leaving only a small mixed radiolucent and radiopaque area in the central region of the interfrontal suture. The radiolucent zone in the previous group was not able to be identified due to complete merging of the radiopaque streaks of both sides of the suture. The re-established normal suture pattern could be noted at the most caudal and cephalic part of the interfrontal suture.

Group D: sacrifice of rabbits 8 weeks complete distraction (Fig 6d). The radiopacity of the expanded gap in this stage kept increasing and achieved a similar level as the native adjacent bone. The radiolucent gap completely disappeared and looked similar to the sham group (Fig 6e). The re-established normal radiographic bony structure of the distraction gap and interfrontal suture were observed without any evidence of defect.

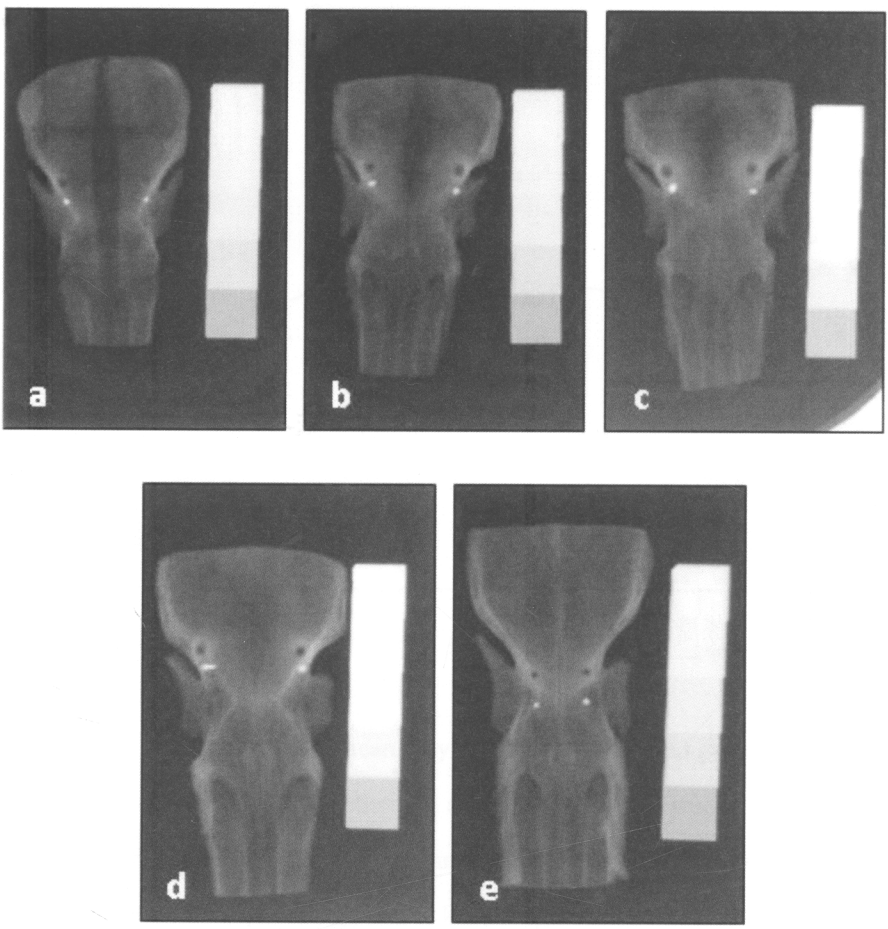


**Fig 6**. Demonstration of the occlusal film radiographic appearance of the distraction suture for the cranial vault at various stages of the experiment. a: at completion of distraction. b, c and d: 2, 4, and8 weeks at complete distraction respectively and e: the sham

Densitometry

Radiographic bone density in the expanded area was quantitatively assessed using a densitometer. Each film was scanned and transferred into a personal computer with image processing and analysis software to calculate the opacity level in the expanded gap as the grey scale value. The radiodensity of the distraction gap in each experimental group was shown in Fig 7. The radiopacity of the expanded gap rapidly increased in group A and gradually increased thereafter. The increasing radiopacity of the expanded gap in group D was almost the same level as the sham group. Statistical analysis of the mean grey level revealed a significant difference in

group A when compared to all groups ($P<0.05$). Where as no significant difference was found among the other groups.

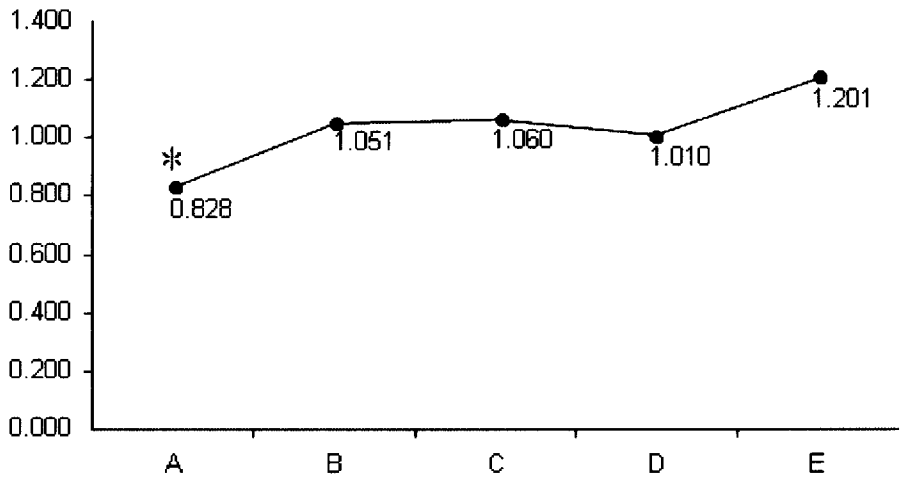


**Fig 7**. The graph demonstrated the mean grey level in the expanded gap in the various experiment groups: A, at completion of distraction; B, at 2 weeks; C, at 4 weeks; D, at 8 weeks complete distraction; and E; the sham. Rapid increasing of the radiopacity was observed after completion of the distraction phase (*$p < 0.05$), and it kept on gradually rising to achieve nearly the same level as the sham group in group D.

Histological finding

The distraction gap and the adjacent bony tissue were processed for an H&E stain and evaluated by conventional light microscopic assessment.

Group A: sacrifice of rabbits at completion of distraction (Fig 8a). The distraction gap was filled with fibroblastic cells which seemed to align themselves palisades to the vector of distraction. Few inflammatory cells were found in the distraction gap. Islands of new bone spicules were already seen throughout the gap. The new bone formation extending from the host bone surface were also noted

Group B: sacrifice of rabbits 2 weeks after complete distraction (Fig 8b). The newly formed bone increased and filled up the distraction space. New trabeculae bone were extended from both the host bone surfaces to the midline. The round active osteoblastic cells with

osteoblastic seams were noticed around the new bone formation area. The amounts of fibroblastic cells decreased.

Group C: 4 weeks after complete distraction (Fig 8c). The distracted intersuture gap was completely filled up with newly formed bone. More mature woven bone was noted with small fibroblastic tissue. Nevertheless, there still were no suture structures established in this stage.

Group D: sacrifice of rabbits 8 weeks complete distraction (Fig 8d). Mature lamellar bone and bone marrow structure were found in the distraction gap, indistinguishable from the native bone stump. The suture -like structure was also observed in the middle part of the distraction gap. The re-established cranial suture structures were nearly similar to that found in the sham group (Fig 8e).

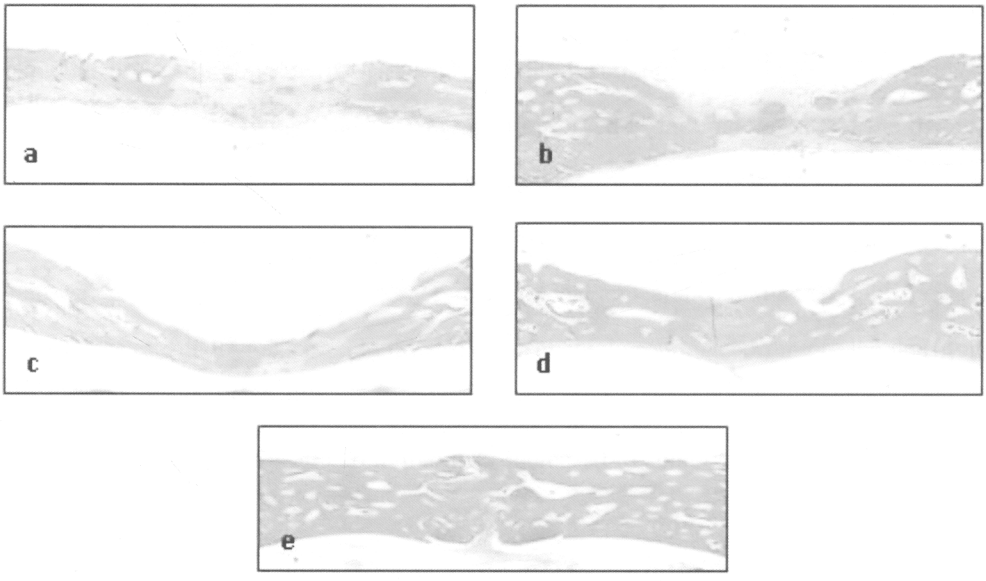


**Fig 8**: Demonstrated histological features of distraction suture of the cranial vault in various stages of the experiment. a: at completion of distraction. b, c and d: 2, 4, and 8 weeks at complete distraction, respectively and e: the sham (H&E stained).

## Discussion

The technique of distraction osteogenesis involves the creation of new bone by gradual separation of two or more bony fragments following their surgical division. This technique can provide unlimited amounts of regenerated bone in the skeleton that still has the potential for fracture healing. In the present study, distraction osteogenesis was applied to expand the growing cranial suture without osteotomy in rabbits. The result of the study demonstrated the feasibility of using the distraction osteogenesis technique to expand cranial sutures without an osteotomy of the growing rabbit calvarium. It resulted in successfully regenerating new bone in the distraction gap with a reestablished normal anatomical cranial suture structure. The regenerated tissue in the distraction gap changed from a soft- fibrous like structure to a bony hard consistency tissue with suture structures in the midline region. The microscopic examination revealed normal mature lamellar bone and bone marrow structures in the distraction gap, as seen in the adjacent native cranial bone. Suture like structures were also observed in the middle part of the distraction gap. The re-established cranial suture structures were nearly similar to that found in the sham group. These findings were also confirmed by a radiographical study. The initial radiolucent expanded gap was replaced with a normal bony radiographical appearance and a re-established interfrontal suture was eventually observed in the last experimental group. According to the densitometry, the amount of new bone formation in the distracted cranial suture started rapidly from the completion of the distraction process and then gradually increased to achieve a normal level in the last group at the 8 week period.

In this study, rabbits served as the models for the distraction process of the cranial suture. Rabbits are cheap, easy to feed, and ethically better accepted for experiments than dogs or sheep. Moreover, because the bone used for the histological section is very small, it was very helpful to analyze a histological picture of the whole distraction area on a single histological section. Although performing the operation on such a small bone is technically demanding, the problem was overcome by using a tiny distraction device modified from microimplants and orthodontic expansion screws. In the present study, microimplants were able to provide sufficiently stable sites as a bony anchorage for direct application of external forces in the process of cranial suture expansion. The bony fixed microimplants of the distraction device could resist the force from the suture structures and the surrounding soft tissue that was against the expanding vector, without bending outward during the distraction period in all groups.

The treatment of craniofacial deformities, which resulted from the lack of growth led to severe deformations such as craniosynostosis, hemifacial microsomia, and small orbits in the anophthalmic orbit, conventionally involved either release of a stenotic attachment in an attempt to correct the deformity within the growth phase or observing the growth until maturation and then secondary correcting the disturbance by means of an osteotomy, bone graft, or a combination of both.[30] Preliminary work has used distraction osteogenesis for cranial expansion after coronal osteotomy in pediatric patients with craniosynostosis.[31] The present study showed successful cranial suture expansion in growing animals without an osteotomy, followed by rapid new bone formation and normal suture being reestablished. This probably resulted from the principle that growth or change at the suture area is a secondary, compensatory, and a mechanically reactive event following the primary growth of the enclosed neural and facial soft tissue matrices, therefore, it is also responsive to external manipulation. The bone of the calvaria is displaced outward by the enlarging brain, and it responds by depositing new bone at the contact edges of the suture.[30] It has also been suggested that sutural expansion involved injury, followed by a proliferative repair phenomenon which, in other tissues, usually leads to the formation of scar tissue. However, the ability of sutural connective tissue fibroblasts to remodel ultimately leads to regeneration of the suture.[1;32-34] This suggested that with the principles of distraction osteogenesis, cranial expansion and growth manipulation may be possible in the growing cranium without using more invasive surgical techniques, such as a craniotomy or surectomy.

## Conclusion

Distraction osteogenesis without an osteotomy could be used in cranial suture expansion with satisfactory outcomes in growing rabbits. Newly formed bone in the distraction gap started forming rapidly since the completion of the distraction phase. The new bone formation kept increasing gradually until it achieved a normal level in the 8 weeks after complete activation group. The re-established cranial sutures possessed the similar clinical, radiographic and histologic features as found in normal cranial suture. Cranial suture expansion using the distraction osteogenesis technique without an osteotomy appeared to be a promising procedure to increase the cranial vault dimension, especially in craniofacial deformity or craniosynostoses patients. Clinical application should be the next step to be studied and evaluated.

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