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Original Article

Shortening of bones using novel contraction osteogenesis device: An experimental study

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Abstract

Aim: Given the high complication rates associated with orthognathic surgery for the correction of maxillomandibular malformations, studies have focused on alternative methods of strengthening the jaw, such as distraction osteogenesis. However, methods of shortening of the jaw are not well-elucidated in oral and maxillofacial surgery practice. This study aims to investigate the efficacy of a new method of shortening osteotomized jaws.

Methodology: A 2.5-3 cm skin incision was made on the left tibia of each of 15 New Zealand white rabbits aged 12–18 months, followed by fixation of 15 mm pre-opened distractor devices to the tibia after osteotomy. After a five-day latency period, the distractors were activated to a total of 8 mm, with closure of the device set at a rate of 0.25 mm/day in the test group. After a five-day latency period, the distractors closed at a rate of 0.125 mm/day, achieving a total contraction of 5 mm. The distractors were not activated in the control group. The bone at the contraction range was evaluated, and the resultant shortening was measured.

Results: The tibia was shortened by an average of 4.32 mm. Exaggerated bone formation was identified around the osteotomized cortical bone in all rabbits in the control and study groups, and there were minimal complication rates.

Conclusion: This study verified that the jaw can be shortened by performing slow, controlled contraction with a bone resorption pattern.

Keywords: contraction osteogenesis, shortening the jaws, distraction device, osteotomy

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Introduction

Although treatments have been applied for the surgical correction of deformities of the maxillofacial area, it is challenging to achieve successful function and optimal aesthetics for patients using conventional methods, such as orthognathic surgery (1-3). A challenge in orthognathic surgery is the inability of the surrounding soft tissues to adapt to the rapid and excessive skeletal movements (4, 5).

The distraction osteogenesis technique is a transcutaneous or transmucosal endosseous application involving the extension of short, discontinuous, deformed bones together with corticotomy of the soft tissue adjacent to the osteotomy (6, 7). Presently, distraction osteogenesis is used in many cases, ranging from patients requiring increased vertical dimension of the alveolar bone to those requiring midfacial advancement (8,9). However, traditional methods, which result in high mortality and morbidity rates, are still being used for the treatment of long craniomaxillofacial deformities, such as hypertelorism, mandibular prognathia, and maxillary hyperplasia. Therefore, there is an urgent need for a less invasive method, such as distraction osteogenesis.

Physicians must develop new surgical methods with fewer complications for shortening or reducing prolonged and/or enlarged structures (10). Contraction osteogenesis involves the use of controlled compression force on osteotomy or corticotomy segments, and this method may be an ideal solution for such patients (11), as it allows treatment of large bones and narrow areas, such as dental and alveolar segments.

This experimental study is based on our pilot study that reported complications associated with contraction osteogenesis in sheep jaw bones (12). The present study aims to investigate whether osteotomized bone segments could be controlled by contraction osteogenesis with a different device and to compare the complication rates with those noted in our pilot study using a different animal model.

Materials and Methods

All experimental procedures were performed in accordance with the ethical guidelines of the International Association for Study of Pain in Animals and approved by the local ethical committee. This study was conducted on 15 young adult New Zealand rabbits with ages of 12–18 months and weights of 2.5-3.5 kg, which were determined to be healthy by veterinary control.

Thirteen experimental animals were divided into two subgroups.

The rabbits in Experimental Group 1 (E1) were euthanized immediately after the end of the contraction stage (n=6).

The rabbits in Experimental Group 2 (E2) were euthanized 30 days after the end of the contraction stage (n=7).

There were two control animals.

C1 (n=1) was euthanized with the E1 animals.

C2 (n=1) was euthanized with the E2 animals.

Design of Contraction Osteogenesis Device

The novel titanium-body external distractor was specifically designed for this study. The device weighs 12 g, and it can be fixed to the bone with pins that can be used to perform the contraction process on the rabbit tibia, with 0.5 mm for each full turn.

The apparatus was affixed to the bone with the help of four external pins with a length of 1.5 mm, total length of 35 mm, and screw length of 10 mm (TRIMED®, Titanium Implant Systems, Ankara, Turkey). These pins were affixed to pin slots in the device.

Surgical Procedure

Food and drink were discontinued 18–24 h before the operation. Intramuscular (IM) anesthesia was administered using 2% xylazine (Rompun, Bayer, Germany; 50 mg/kg) and ketamine hydrochloride (HCl) (Ketalar, Eczacıbası, Turkey; 5 mg/kg). Following anesthesia, ampicillin-sulbactam sodium (Sulcid, IE Ulugay, Istanbul, Turkey; 80 mg/kg) was administered via IM injection to prevent infection.

A skin incision approximately 2.5–3 cm in length was made on the medial portion of the tibia, parallel to the tibia long axis. The subcutaneous tissues were dissected by blunt dissection, and the part corresponding to the osteotomy site was carefully stripped from the bone in a way that would not damage the periosteum. A guide incision was created under saline cooling to determine the osteotomy line in the outer cortical bone just below the point where the tibia was connected to the fibula using a thin fissure bur.

Before the osteotomy was fully formed, the distraction devices, which were adjusted on both sides of the bone incision at a distance of 15 mm in advance, were placed in the fixation pins fixed at equal distances on both sides of the bone incision. In addition, two micro screws 1.5 mm in diameter and 5 mm in length (TRIMED®; Titanium Implant Systems) were placed to objectively measure the shortening created by contraction of 3-4 mm lateral to the outermost pins on both sides of the incision used for fixation of the distractor (Fig. 1).

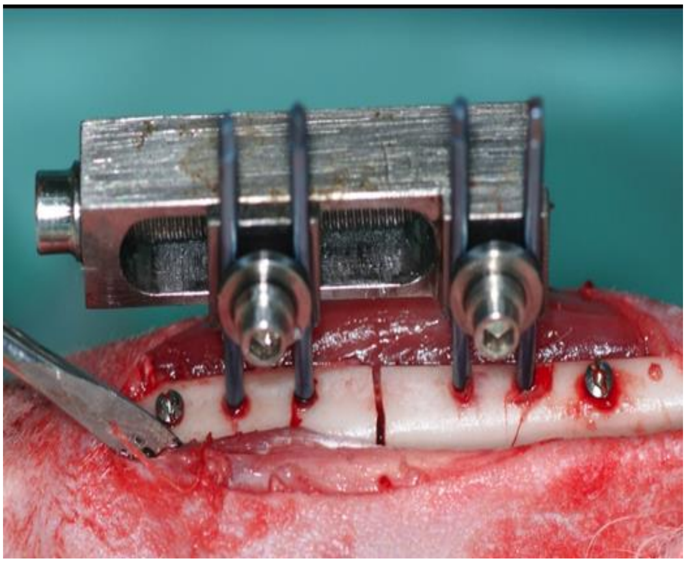

Figure 1. Osteotomy line at the outer cortical bone. Distraction devices, adjusted on both sides of the bone incision at a distance of 15 mm in advance, are placed.

All animals were allowed to recover for 5 days postoperatively to allow healing of the wound on the surgical site and osteoid callus formation on the osteotomy line. At the end of the 5-day latent phase, the distractor was placed 15 mm open on the left tibia of the rabbits and was initially activated to close 0.25 mm (1/2 round) once a day.

In order to achieve a total 5 mm contraction, activation was continued over 40 days. No activation was performed in the control group animals, and the normal osteotomy was allowed to heal. Animals in Experimental Group 1 and one animal from the control group were sacrificed immediately after the end of the contraction, and animals in Experimental Group 2 and the other control animal were sacrificed one month after the end of the contraction. The distance between the micro screws placed to measure the shortening in the animals with a removed tibia was measured by an independent physician who was not involved in the experimental procedures up until this stage (Fig. 2).

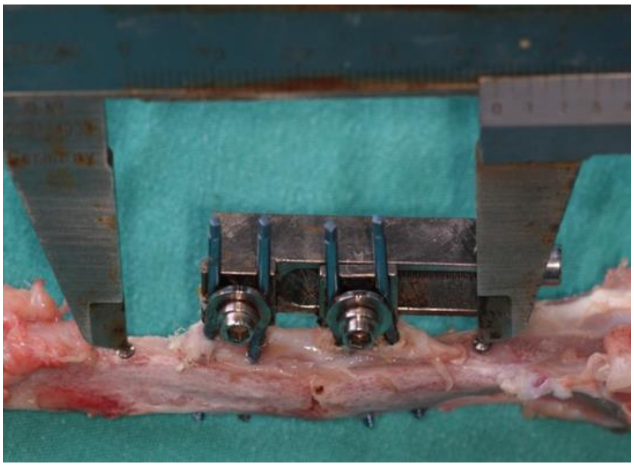

Figure 2. Macroscoping findings of experimental models.

Statistical Analysis

In this study, all numerical data were presented as mean ± standard deviation. Conformity of the data to the normal distribution was controlled by the Shapiro-Wilk test. The Independent Two-samples t-test was used for comparisons of differences amongst groups. In statistical analyses, the confidence interval was accepted as 95%, and the significance level was set at $p<0.05$. All statistical analyses used in the present study were performed with SPSS Software version 22.0 (IBM Corp., Armonk, NY, USA).

Results

Macroscopic Findings

In the C1 rabbit, accumulation of callus formation was seen, especially at the posterior incision. As there was no activation of the device, there were no signs of deviation and rotation of the rabbit tibia bone. Therefore, the length between the two screws calculated after the sacrifice was not different to the length measured during the surgery to place the device.

In the C2 rabbit, which was sacrificed 30 days after the contraction stage, the callus formation had disappeared, and the osteotomy line had fully healed, so the tibia had reverted back to the previous preoperative status. Generally, in the Experimental Groups (E1 and E2), bending of the pins related to the extended line was observed. Diversion through each segment and cortical osteotomy and rotation were not seen in most animals. Especially in the E2 rabbits, the tibia was healed with full remodelation. Nonetheless, more callus formation without full remodelation was observed in the E1 rabbits.

Two E1 rabbits and one E2 rabbit with abnormal ranges of contraction were excluded from the study due to important complications. These complications were: 1) “V” shape rotation, 2) the drifting of segments into each other, and 3) osteotomy-related intimately pins on the cortical bone (Fig. 3).

The Shapiro-Wilk test results revealed that the contraction rates obtained were normally distributed ($p>0.05$) (Table 1). In our evaluation of the mean value of the contraction, there was no statistical difference between the E1 and E2 groups ($p=0.634$). The contraction rates were not affected by whether or not we waited 30 days after the end of the contraction process.

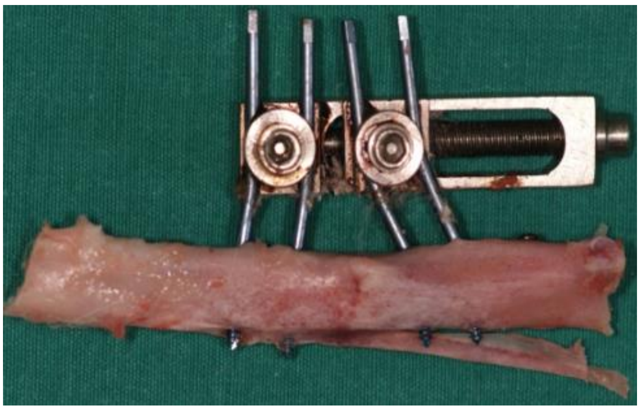

Figure 3. Common complication as "V" Shape Rotation.

Table 1. Descriptive statistics for contraction rates in experimental groups

	Exp. Groups	N	Mean	Std. Deviation	Std. Error Mean	p
Contraction Value	E1	4	3,13	0,63	0,31	p>0.05
	E2	6	2,92	0,67	0,27	

Histological Findings

Histological examinations of the horizontal sections taken immediately following the end of the contraction period (40 days after the osteotomy) showed new bone formation in the inner parts along the osteotomy line and an exaggerated callus formation in the outer parts of the osteotomy line in the C1 rabbit (Fig. 4).

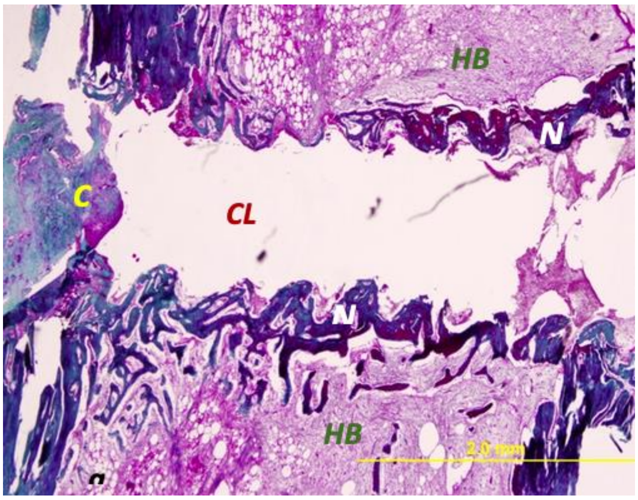

Figure 4. Histologic examinations

a. C1 (Masson staining, 4×)
C: callus formation, HB: host bone,
N: new bone tissue, CL: corticotomy line

In the experimental groups, the horizontal sections obtained after contraction revealed fibrous pseudoarthrosis in the inner part of the section and hyaline cartilage formation around this structure. In the E1 rabbit, which was sacrificed immediately after contraction, fibrous arthrosis and hyaline cartilage were formed around the contraction area.

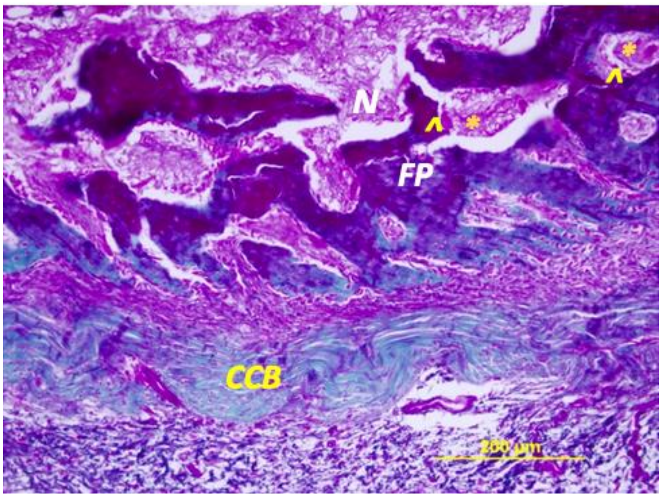

Figure 5. Histologic examinations
a. E1 (Masson staining, 20×)
CCB: transformation from callus to cortical bone,
CB: cortical bone, FP: fibrous pseudoarthrosis
*: osteoclasts, ^: Howship’s lacunae

While osteogenic activity was observed in the areas close to the contraction area, osteoclasts and calcified new bone cells were found together. In addition, Howship’s lacunae, which represents evidence of bone resorption, were observed in this region by compression forces.

Histological examinations performed on the horizontal sections taken from the E2 rabbits sacrificed one month after surgery showed that parts of the fibrous osteoarthrosis in the contraction zone decreased and converted into new bone tissue with hyaline cartilage. Fibrous cartilage forming the dark green parts stained with Masson dye in the horizontal sections taken from the E2 rabbits gradually decreased in some rabbits where the healing was fast, and it was replaced with normal pink bone tissue (Fig. 5).

Discussion

Greensmith et al. firstly described contraction osteogenesis as a procedure to correct and reshape deformed calvarium using reverse forces with distractor devices. The procedure was performed on three cases without any brain pressure or well-known neurological complications associated with other intracranial surgical procedures, revealing very important knowledge, and surgeons were encouraged to use this procedure for different areas (13).

Castello et al. proposed the concept of contraction osteogenesis to develop an inverse solution for shortening or reducing enlarged structures. They described the contraction osteogenesis method as the shortening of bone structures by inducing new bone formation or remodeling by the application of external compression forces, taking advantage of craniofacial growth potential and without the need for osteotomy. In their study, they used 26-day-old rabbits and managed to significantly shorten the facial region by applying a contraction to the mid-face region without applying a corticotomy or osteotomy (14).

The only similar study to the present study is the study by Li et al. on contraction osteogenesis in six goat mandibles.11 This article, for which only the abstract could be obtained, reported that an osteotomy was made at the angle of the goat mandible, and the devices developed by the investigators enabled 0.5 mm of shortening in 3 days and 1.3 cm in 78 days. In a microscopic evaluation, fibre, cartilage, and bone layers were observed, in that order, from the center outward (11).

The contraction rate reported by Li et al. was lower than that found in the present study, and more contraction was obtained in a shorter time (11). Apart from the presence of some local cortex osteotomies, the present contraction procedure was successful. The microscopic results of our study were quite similar. In the histological sections examined, the formation of fibrous pseudoarthrosis and hyaline cartilage formation around on structure were observed. Immediately after the end of the contraction, the rabbits that were immediately sacrificed (D1) had the most internally fibrous pseudoarthrosis in the contraction zone and hyaline cartilage around it. The osteogenic activity was observed near the contraction area, and osteoclasts and calcified new bone cells were contracted together. In the E1 rabbits, the osteoclasts increased suddenly with the initiation of the contraction force. Howship's lacunae, which represent evidence of bone resorption and shortening of the bone, were also seen in this region.

In the sections taken from the rabbits sacrificed one month after the end of the contraction (E2), the fibrous pseudoarthrosis sections in the contraction zone had decreased and transformed into new bone tissue with hyaline cartilage. Fibrous cartilage regions had completely disappeared in some E2 rabbits with maximum recovery. Furthermore, osteocytes occurring in new bone production and bone trabecula were observed in these subjects. In addition, in E2 rabbits, the callus had gradually started to return to normal bone tissue after the compression forces were removed. Histologically, there was a significant increase in osteoblastic activity in the contraction zone, and no evidence of osteoclastic activity was observed.In the intra-oral contraction we performed in our pilot study, complications such as inadequate stability, infection of the contraction zone, bone necrosis, cortical bone osteotomies, maintenance difficulties, pin losses, and pin tract infections were observed. Therefore, in the present study, an external distractor was selected, which was easy to maintain and provided a more rigid fixation, and thick pins were used for stability.

The most common complication in this study was medial rotation in the distal segment due to the compression force and shifting of the segments on each other. Factors that may cause this problem include resistance of the segments connected to the compression force and slight bends in the pins, as well the fact that the tibia of rabbits are frequently used for movement, and thus forces on the contraction zone are increased (12). Moreover, the cortical bone in the rabbit tibia is much thicker than the medullary bone. Additionally, the external distractor was surrounded by the tibia distractor with a flexible wrap to protect it from external factors. Only three animals experienced excessive shortening due to deviation. Only one rabbit had a mild infection which was controlled by antibiotics.

In this study, we investigated the effectiveness of our novel contraction technique for shortening of the tibial bone in rabbits. Although we encountered complications, this study proved that our new device could shorten bones in a controlled manner (average shortening 4.32 mm). At this stage, we do not believe that the clinical use of contraction osteogenesis will become as widespread as distraction osteogenesis. However, experimental studies on this subject should be accelerated, the rhythm and speed of contraction should be clearly defined, and ideal contraction principles should be clarified. Furthermore, we believe that contraction osteogenesis can be implemented in the clinical setting for shortening of the cortical bone in maxillary prognathism and maxillary deep bite patients.

Conclusions

This study proved the bones are possible to shortened with perform controlled, slowly contraction forces with using bone resorption patterned and the other tissues such as soft tissues, nerves, blood vessels adapted the new positions successfully like a distraction osteogenesis rather than the osteotomies.

Acknowledgments: This study was presented as a full-text oral presentation at the 1st International Dental Research and Health Sciences Congress held between 20-22 May 2021.

Ethical Approval: Ethics committee approval was received for this study from Human Ethics Research Committee International Association for Study of Pain in Animals and were approved by the local ethical committee. This study approved by Department of Scientific Research with grant number: TSD-09-1104

Peer-review: Externally peer-reviewed.

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Conflict of Interest: No conflict of interest was declared by the authors.

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