Is It Possible to Shorten the Jaws Using Contraction Osteogenesis?

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Purpose: This study investigated whether shortening of osteotomized jaws is possible.

Materials and Methods: Nine sheep were used (2 as controls and 7 as experimental subjects). Distraction devices that had previously been activated to 10 mm were fixed to the mandibles of all animals bilaterally and used in reverse as a contraction device. Control and experimental animals were sacrificed at 1 month and 3 months. Bone in the area of contraction was evaluated using radiodensitometry and microscopy.

Results: The mandibles were shortened an average of 5.5 mm. Exaggerated bone formation was seen around the osteotomized cortical bone. When histologic slices from experimental animals were examined 1 month after the contraction period, fibrous pseudoarthrosis formation was seen centrally, with hyaline cartilage around it, whereas normal bone formation was seen in the outer part. The hyaline cartilage had turned into normal bone 3 months after the end of contraction.

Conclusions: It is possible to shorten bones using contraction osteogenesis.
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Distraction osteogenesis is a biological process of new bone formation between the surfaces of bone segments that are separated gradually using incremental traction.[1] Over the past 20 years, distraction osteogenesis has emerged as a useful alternative for managing dentofacial deformities because of its simplicity and low morbidity compared with conventional surgical techniques.[2] However, craniomaxillofacial deformities caused by excessive bone quantity, such as hypertelorism, maxillary hyperplasia, or mandibular prognathism, are typically treated with traditional surgical osteotomies despite considerable morbidity.[3-5] Currently, these patients cannot be treated with less invasive methods such as distraction osteogenesis. Conventional surgical methods give rise to complications such as nerve damage, bleeding, undesired fractures, and temporomandibular joint problems and require rigid fixation. To decrease the complication rate, it is essential to develop new procedures with low morbidity to treat dentofacial deformities caused by excessive or enlarged bony areas. Contraction osteogenesis, which can be defined the application of an external compression force to osteotomized bone segments to shorten bone structures, may be a new solution for these patients.[6] Because everything in the universe has an opposite, the possibility of controlled contraction and controlled distraction should be no surprise.

This experimental study examined whether osteotomized jawbones could be contracted in a controlled fashion. The intent was to develop the concept of contraction osteogenesis in maxillofacial surgery. The results of this pilot study were positive and improvements of the method are planned.

Materials and Methods

The protocol and guidelines for this study were approved by the animal care and use committee. Nine healthy adult female sheep were used under veterinary supervision. Animals were assigned randomly to the control (animals C1 and C2) or experimental (animals E1 to E7) group.

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To accomplish contraction osteogenesis, intraoral bone-borne distraction devices consisting of an 11-mm rapid palatal expander (GAC International, New York, NY), which has 4 holes for bone attachment, were used (Fig 1).

The animals were fasted for 1 day preoperatively. For anesthesia, the sheep were given intramuscular xylazine (Rompun 2%; Bayer, Istanbul, Turkey) and ketamine HCl (Ketalar; Eczacibasi-Warner-Lambert, Istanbul, Turkey). To prevent infection, antibiotics were given intraoperatively and for 5 consecutive days postoperatively. All surgical procedures were carried out under conditions of asepsis and antisepsis. Local anesthesia was administered at the operating site for hemostasis and postoperative pain decrease. Analgesics were administered postoperatively. For oral hygiene, oral saline irrigation was performed daily until completion of the contraction osteogenesis procedure. All sheep were fed a soft diet postoperatively.

SURGICAL PROCEDURE

All surgical procedures were performed with a bilateral intraoral approach. A crestal incision with a vertical release was made over the edentulous area of the mandible and a flap was elevated. The body of the mandible was exposed and a corticotomy was performed just in front of the first premolar with a surgical reciprocating saw under irrigation. Then, a distraction device that had been activated 10 mm previously was fixed to the mandible with bicortical titanium screws and the bone division was completed manually with a mallet and small osteotome until segment movement was observed (Fig 2). To measure bone shortening macroscopically, a monocortical miniscrew was inserted on either side of the osteotomy line as a marker and the distance between the screws was measured (Fig 3). Then, the surgical exposure was closed primarily (Fig 4).

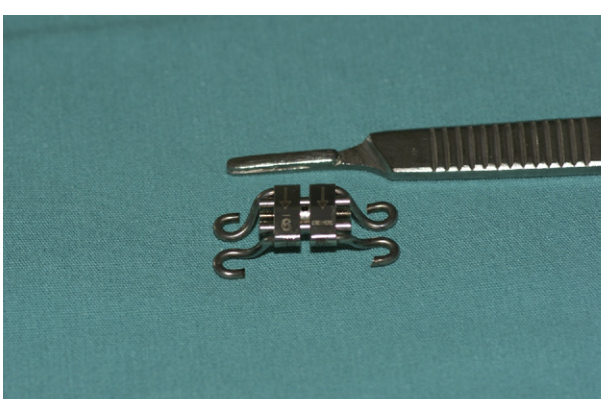

FIGURE 1. Device used for contraction osteogenesis.

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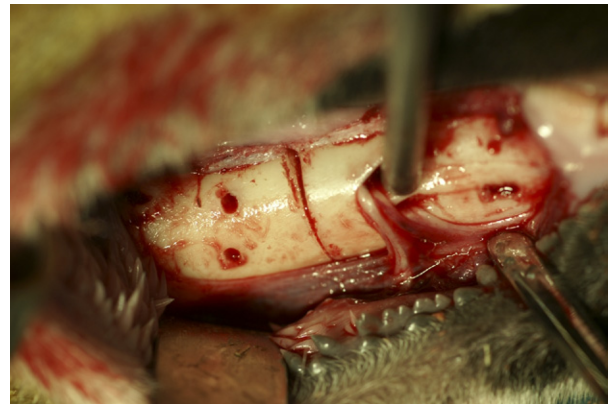

FIGURE 2. View of the mental nerve, osteotomy line, and miniscrew holes.

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After a latent period of 7 days, the distraction device was activated 0.5 mm/d for 8 days by closing the device. The contraction rate was then decreased to 0.25 mm/d for another 16 days because of the increase in compression strength. The aim was to achieve 8 mm of contraction in total. The distractors of the control group were kept in place without activation.

One month after completing the contraction period, 3 animals from the experimental group and 1 animal from the control group were sacrificed; the remaining animals were sacrificed 3 months after the contraction period. The distance between the marker miniscrews was measured on the harvested mandibles. To assess the volumetric density of the regenerated bone, the excised mandible was scanned using quantitative computed tomography. The bone specimens were decalcified in 10% formic acid, embedded

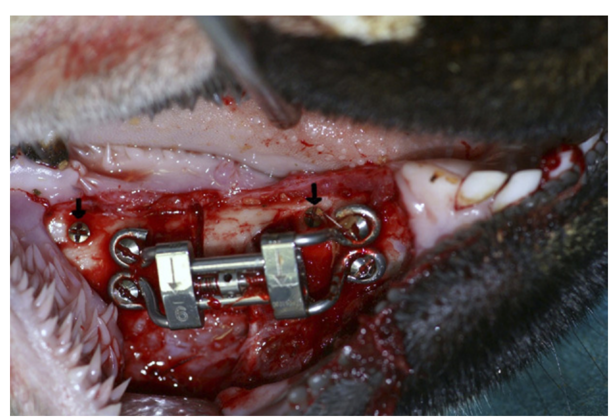

FIGURE 3. Distraction device fixed to the mandible. *Black arrows* show the marker miniscrews.

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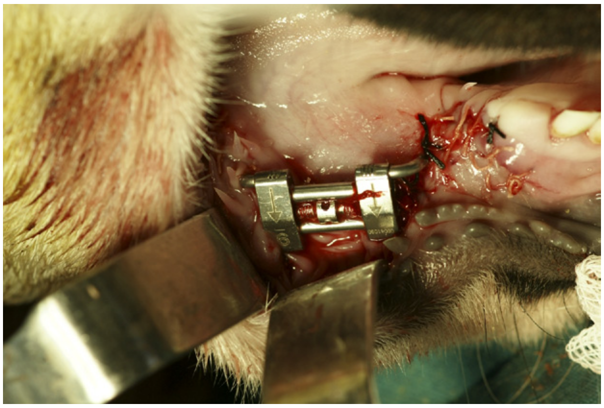

FIGURE 4. View of the device after primary wound closure.

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in paraffin, cut into sections, and stained with hematoxylin and eosin for histologic investigation.

Results

MACROSCOPIC FINDINGS

In the experimental group, there was resistance to the contraction forces during activation of the distractors. Nevertheless, the distractors were activated in the closing direction without problems in all animals. After the contraction period, some miniscrews in the distractors had loosened because of the contraction forces or secondary infection in 4 hemimandibles of 3 animals.

In the experimental group, extraoral examination showed that the amount of bone contraction was not reflected in the soft tissues. This might arise from the small amount of contraction, deviation of the distraction vector, or the long distance between the lower lip and incisors, unlike the human anatomic situation.

Macroscopic examination of the harvested mandibles showed compact callus formation around the osteotomy area, especially on the vestibular side and at the basal part of the mandible (Fig 5). In addition, local cortex fractures were observed in 5 animals resulting from bone resistance to the contraction forces, but these small fractures did not affect the contraction procedure.

On the harvested mandibles, the distance between the marker miniscrews was measured and the amount of contraction was calculated by comparing the pre- and postoperative measurements. The amount of contraction could not be measured in the hemimandibles of 3 animals because the marker miniscrews had loosened. The contraction averaged 5.5 mm.

RADIODENSITOMETRIC FINDINGS

Eighteen hemimandibles in 9 animals were evaluated using radiodensitometry of the frontal slices of computed tomographic images. In all hemimandibles, the images were taken 1 mm mesial and 1 mm distal to the osteotomy line. The cortex and medulla were measured in all images and the arithmetic means were compared statistically (Fig 6). In addition, the cortex and medulla of bone in the molar region were measured in a slice taken away from the contraction area. As a result, there were radiodensitometric evaluations for 5 different groups: control at 1 month, control at 3 months, experimental at 1 month, experimental at 3 months, and molar region. Depending on whether the underlying distribution was normal, parametric or nonparametric methods were used. Student t test or the Mann–Whitney U test was used to compare 2 groups and 1-way analysis of variance or the Kruskal-Wallis test was used to compare the 3 groups. Dunn and Tukey tests were also used.

The difference in bone density between 1 month and 3 months was statistically significant. The bone density in the contraction area decreased initially and then increased to normal at the end of 3 months (Table 1).

HISTOLOGIC FINDINGS

Normal bone healing was observed in animals C1 and C2 1 month and 3 months, respectively, after the end of the contraction period.

In the shortened mandibles examined 1 month after the end of contraction (animals E1 to E3), cen-

FIGURE 5. Exaggerated callus formation.

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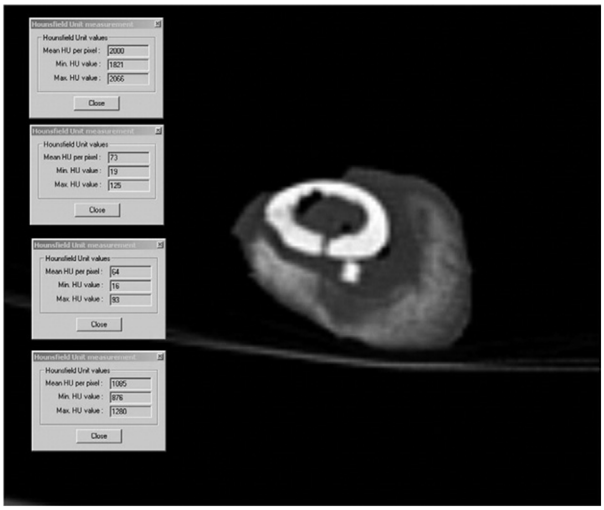

FIGURE 6. Computed tomographic image of contraction area.

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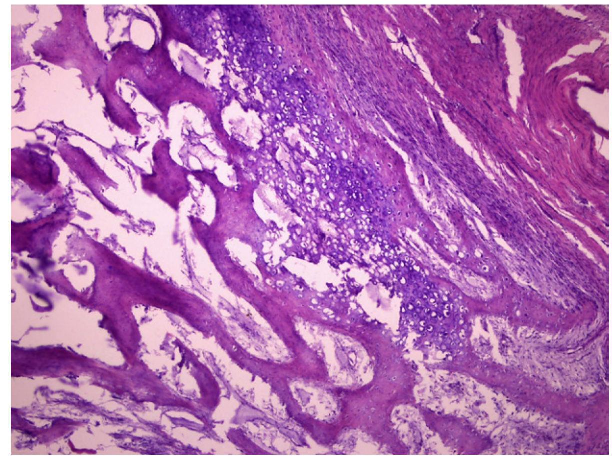

FIGURE 7. Fibrous pseudoarthrosis formation and surrounding hyaline cartilage.

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trally, fibrous pseudoarthrosis formation surrounded by hyaline cartilage was observed histologically. Normal bone formation was seen outside this area (Fig 7). Simultaneously, vascular deformation was seen in the contraction area. In the animals sacrificed 3 months after the end of the contraction period (E4 to E7), normal bone formation was seen (Fig 8). The fibrous pseudoarthrosis and hyaline cartilage that was seen in animals E1 to E3 had converted completely to bone. In addition, vascular formation was observed in the contraction area. Marked callus formation was seen in all experimental animals. In E5, normal bone healing occurred, although some leukocyte infiltration was seen because of a secondary infection.

Discussion

Distraction osteogenesis, currently a standard method of bone lengthening, is less invasive and time intensive and has a significantly lower morbidity rate than traditional methods of craniofacial reconstruction.[7,8] The sudden changes in bone and soft tissues with surgery have negative effects on the chewing muscles, the temporomandibular joint, occlusion, feeding, and breathing. The controlled, slow migration of soft tissue and bones, rather than sudden displacement, has adaptive effects on stomatologic functions. Apart from these principles, this study examined whether controlled reduction of an osteotomy in sheep jawbones was possible by closing a

Table 1. STATISTICAL ANALYSIS OF CORTEX AND MEDULLA VALUES

Groups	Cortex	Medulla
Molar region	1,976 (1,717-2,024)	−58 (−111 to −8)[a]
Control at 1 mo	2,002 (1,768-2,159)	70 (44-97)[b]
Experimental at 1 mo	1,867 (1,182-2,178)	68 (−936 to 184)[b]
P value	.079	<.001
Molar region	1,667 ± 163[a]	49 (20-176)[a]
Control at 3 mo	1,225 ± 131[b]	272 (149-385)[b]
Experimental at 3 mo	1,185 ± 191[b]	139 (54-1,099)[b]
P value	<.001	<.001
Experimental at 1 mo	1,767 ± 300	68 (−936 to 184)
Experimental at 3 mo	1,185 ± 191	139 (54-1,099)
P value	<.001	<.001
Control at 1 mo	1,995 ± 137	70 (44-97)
Control at 3 mo	1,224 ± 131	272 (149-385)
P value	<.001	.002

NOTE. Values are presented as arithmetic mean ± standard error or median (minimum-maximum). Different superscript letters indicate a statistical difference at $P < .001$.

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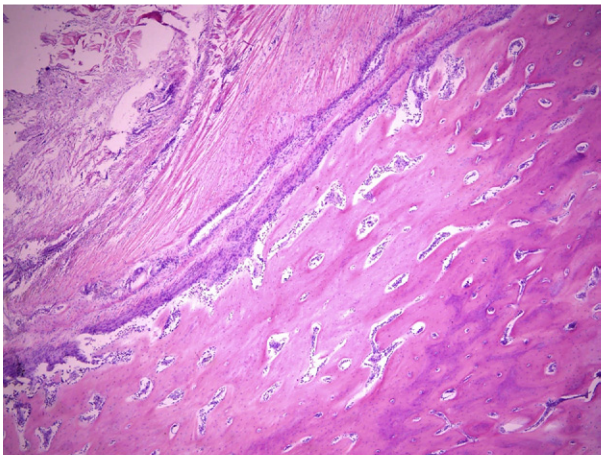

FIGURE 8. Normal bone formation was seen 3 months after the end of contraction.

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distractor in a manner opposite to distraction osteogenesis.

Much experimental and clinical research of bone has been conducted since the first description of distraction osteogenesis. In contrast, there have been few reports on contraction osteogenesis, which is a recent concept.[6,9-12] Most reports concerned cranial bones (3 case reports and 1 experimental study),[6,9,10,12] and only 1 was an experimental study of maxillofacial surgery.[11] The latter study, written in Chinese, was not published in a Science Citation Index journal.

Greensmith et al[9] treated 3 sagittal synostosis cases with cranial compression involving reverse distraction. They devised a new method of providing active, but gradual, correction of sagittal synostosis using cranial compression with a commercial craniofacial distraction device. They found that this method involved less morbidity, required less blood transfusion, and had a shorter operating time. In fact, the method of Greensmith et al resembles transport distraction. As a result, this technique is not a contraction osteogenesis procedure, but can be called reverse distraction. In a similar study, Komuro et al[10] applied combined distraction and contraction osteogenesis to treat sagittal synostosis and achieved satisfactory results.

Staffenberg et al[13] showed the feasibility of distraction at young ages without the need for osteotomies or corticotomies, taking advantage of the osseous remodeling capability and the potential for craniofacial growth. In light of their findings, Castello et al[6] hypothesized about the possibility of achieving the reverse effect, ie, bone shortening or contraction, with a controlled intervening vector of contraction. They implanted an external fixator in the midface of rabbits without a corticotomy or osteotomy and accomplished a significant degree of facial shortening using a contraction schedule. Castello et al[6] based the hypothetical mechanism of contraction osteogenesis on the functional matrix principle described by Moss and Salentijn. The tension applied to the bone by the contraction force may induce osteogenesis, mediated by a mild decrease in vascular flow, resulting in remodeling of the growing bone.

The present experimental study was based on totally different principles from the studies cited earlier. The present concept is "bone compression," which is a method using the advantages of bone resorption seen with osteolysis and bone healing and applying compression to a bone interspace or osteotomy area, ie, no bone growth is involved.

The only study that was considered similar to the present study is by Li et al[11] on contraction osteogenesis in 6 goat mandibles. This Chinese-language article, for which only the abstract could be obtained, reported that an osteotomy was made at the angle of the goat mandible and devices that the investigators developed enabled 0.5 mm of shortening in 3 days; they shortened the mandibles by 1.3 cm in 78 days. In earlier radiographs, the bone density in the contracted area seemed to be decreased and subsequently showed progressive improvement. In a microscopic evaluation, fiber, cartilage, and bone layers were observed, in that order, from the center outward. Subsequently, the cartilage layer turned into bone and ultimately all layers turned into bone during fixation. As a result, Li et al[11] defined contraction osteogenesis as a compression, absorption, and remodeling process and stated that shortening of the mandible with a corticotomy using contraction osteogenesis was possible. Microscopically, the present study obtained similar results. Fibrous pseudoarthrosis was observed at 1 month centrally, with hyaline cartilage around this area, and normal bone in the outer layer. After 3 months, all cartilage had turned into normal bone. Radiographically, the bone density was normal at the end of the consolidation period. The contraction rate reported by Li et al[11] was lower than in the present study, and more contraction was obtained in a shorter time. Except for local cortex fractures, the present contraction procedure was successful. When this contraction rate is applied to the more spongiose bone found in humans, the procedure should be free of problems.

The most frequent complication in the present study was local bone fractures in the vestibular cortex around the distractor screws. Possible causes of this problem are that *1*) the sheep mandibular cortex is thicker than in humans, *2*) the ratio of cortical to medullary bone is too great, *3*) the compression rate (0.25 mm/d) was excessive for this thick cortical bone, *4*) resorption of the vestibular cortex was

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caused by secondary infection, thus weakening the bone, and 5) the screw holes created nonresistant areas in the cortex. To avoid this complication in future studies, using more spongiose bone in nonruminating animals, using more rigid external distractors, and shortening the contraction rate would be useful.

In conclusion, in the present study, a method similar to distraction was applied, but using opposite controlled forces, and whether there were resorption and shortening in bones under compression was analyzed. In each subject, the distractor was closed by a total of 8 mm and an average of 5.5 mm of shortening was obtained. Contraction osteogenesis likely will not be used as widely as distraction osteogenesis.

Although complications occurred, this study demonstrated the feasibility of the controlled shortening of bone. Further experimental studies are needed. For example, the rhythm and speed of contraction, adaptive effects on nerves, muscles, and mucosa, and basic principles of contraction should be determined. Clinical application of this method after further experimental studies is anticipated. For example, in a Class III mandible, contraction osteogenesis after bilateral extractions could be used instead of a sagittal split osteotomy. In a gummy smile, contraction can be used to make a more controlled vertical correction than with a Le Fort I osteotomy. In maxillary hyperplasia, the maxilla can be reverted using contraction osteogenesis rather than a complex Wasmund osteotomy. Furthermore, the contraction method might be applied to dental and alveolar segments.

In maxillofacial surgery, minimal morbidity is a basic goal of every surgical procedure. The present results might be extended to minimize the complications in osteotomy cases in patients with maxillofacial deformity. We believe that the present research can have a widespread effect.

Acknowledgments

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