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Differences in mandibular distraction osteogenesis after corticotomy and osteotomy

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Abstract

Corticotomy or osteotomy was performed on opposing sides of the mandibles in 18 goats. A custom-made distractor was used to lengthen the mandible at a rate of 1 mm/day for 10 days (total 10 mm elongation). Six goats were sacrificed respectively at 2, 4 and 8 weeks after completion of distraction. The distracted calluses were harvested and processed for radiographic, histologic, and scanning electron microscopic evaluation as well as Ca/P ratio analysis. The regenerate bone in the corticotomy side showed more bone formation and earlier mineralization than in the osteotomy side. The results of this study suggest that preservation of intramedullary vessels is beneficial to bone regeneration following mandibular osteodistraction, and that performing corticotomy may be a simple but effective way to promote the maturity of the distracted callus and shorten the time for fixation.

Keywords

mandibular distraction; bone regeneration; corticotomy; osteotomy

Introduction

The technique of distraction osteogenesis was applied first in orthopaedic surgery for long-bone lengthening and was subsequently utilized in the treatment of craniofacial microsomia and bony defects. Both corticotomy and osteotomy are used for bone separation prior to distraction. However, a number of studies have emphasized the importance of corticotomy in long bone distraction. For example, Ilizarov^{6,7} suggested the indispensability of preservation of intermedullary blood supply during limb lengthening. Conversely, Kojimoto et al.¹⁰ reported that the osteogenic potential for bone regeneration derived from the periosteum, and that preservation of the periosteum at the osteotomy site is essential. Moreover, the mode of

distraction osteogenesis remains controversial, and little is known about the effect of preservation of intramedullary vessels on bone regeneration after mandibular distraction.

The objective of this study was to evaluate the differences in bone regeneration following mandibular distraction after corticotomy and osteotomy in a goat model.

Materials and methods

A total of 18 young adult male goats weighing 20–25 kg were used in this study. Twelve weeks prior to performing the distraction protocols, the lower premolars of all goats were extracted bilaterally. All animals were anaesthetized with an i.v. injection of pentobarbital (35 mg/kg) and local administration of 1.0% lidocaine. A skin incision was made along the sub-mandibular region, the periosteum was incised longitudinally along the inferior margin of the mandible and elevated carefully. A custom-made extraoral distractor was placed in the mandible with screws. On one side of the mandible, a corticotomy was performed anterior to the first molar with a small burr under constant saline irrigation. The superior, buccal, lingual and inferior cortex were cut circumferentially around the entire mandible. Great care was taken to preserve the intermedullary tissues and surrounding periosteum. The opposite side of the mandible in the same animal was subjected to complete osteotomy, again preserving the periosteum. Total mobilization was accomplished using an osteotome.

Following a latency period of 7 days, the distractors were activated at a rate of 1 mm/day (0.5 mm every 12 h) for 10 days. Clinical and radiographic examinations were taken to confirm bone elongation (10 mm) after distraction. Six goats selected at random were sacrificed respectively at 2, 4 and 8 weeks post-distraction.

After careful dissection of the soft tissue, the distracted callus was cut in the axial plane. The upper half was fixed in 10% buffered formalin, decalcified in formic acid, trimmed and embedded in paraffin. Fifteen serial sections, 5- μ m thickness, were cut and stained with haematoxylin and eosin. The lower half specimen was fixed in 2.5% glutaraldehyde, dehydrated in a graded concentration of ethanol and dried. These specimens were sputter coated with gold palladium and examined by scanning electron microscopy (AMRAY 1845 FE, USA) equipped with an energy dispersive X-ray microanalyser (ASSY 700P424-1, Tracor-Northern Co., USA). Elemental analysis was applied to obtain the concentration of mineral within the matrix of the regenerated bone and to quantitatively assess the composition of the newly formed bone⁴. The calcium and phosphorous counts per unit area were obtained and the Ca/P ratios for both the corticotomy and osteotomy sides were calculated and averaged. For statistical analysis, the level of significance was determined at $P < 0.05$ by Student's *t*-test.

Results

Clinical and radiographical observations

All animals showed an apparent protrusion of the mandible and an increase in bone length at the end of distraction and during the period of fixation. At sacrifice, the distracted callus was

clearly visible in the elongated mandible, however no obvious difference in the shape of the distracted callus was observed between the corticotomy and osteotomy sides.

The radiodensity in the distraction gap of the corticotomy side was found to be greater than in the osteotomy 2 weeks after distraction (Fig. 1A). After 4 and 8 weeks of healing, the centripetally advancing mineralizations of the distracted zone was observed at both sites, however some differences in radiodensity of the distracted callus were still visible between the two sides. Furthermore, the osteotomy sites appeared to show greater formation of periosteal callus when compared with the corticotomy sites at either 4 weeks or 8 weeks post-distraction (Fig. 1B and C).

Histological findings

At 2 weeks postdistraction, the new bone trabeculae formation began showing continuity in the centre of the distraction gap. However, fibrous tissue in the osteotomy side was greater than in the corticotomy side (Fig. 2A and B). The vast majority of new bone formation resulted from intramembranous ossification in both distracted sites, while only a few chondrocytes were found in two out of six specimens from the osteotomy side (data not shown). The distraction gap after 4 weeks in both sides was supplanted with longitudinally oriented woven bone. In the corticotomy side, the medullary cavity occupied by red marrow was observed extensively. The newly formed bone trabeculae appeared to be more mature and thicker in the corticotomy side than in the osteotomy side (Fig. 2C and D). At 8 weeks, the maturation of the regenerate bone progressed towards a lamellar structure. Fatty marrow filled the newly reformed medullary cavity (Fig. 2E). Similarly, the corticotomy side revealed more mature appearance of bone tissue when compared with the osteotomy side.

According to the method reported by Alberius et al.¹, a histological grading system (Table 1) was used to assess the differences in bone regeneration among 2-, 4- and 8-week specimens. The results of histological grading analysis are shown in Tables 2 and 3. Those data suggested that the corticotomy distraction resulted in more bone regeneration and earlier development of bone marrow than the osteotomy distraction.

Scanning electron microscopy (SEM)

SEM examination confirmed the calcification of the extracellular matrix in distracted callus from both sides of the mandible. Although no gross difference was found in the pattern of mineralization between the two sides after 2 weeks, the crystal formation on the surface of the collagen fibres in the corticotomy side was more dense and regular than in the osteotomy side (Fig. 3A and B). At 4 and 8 weeks of the healing process, a large amount of new trabecular bone and extended mineralization of extracellular matrix were observed; the regenerated bone from the corticotomy side showed higher density and more mature appearances when compared with the osteotomy side (Fig. 3C, D, E and F).

Energy dispersive X-ray microanalysis

The Ca/P ratio of normal mature goat mandibular bone and the mean Ca/P ratios for both the corticotomy and osteotomy sites are shown in Table 4. Statistical analysis demonstrated that the differences in the mean Ca/P ratios between corticotomy and osteotomy were significant

($P<0.05$). It suggests that the corticotomy distraction creates earlier mineralization in the regenerate bone than the osteotomy distraction.

Discussion

In the craniofacial skeleton, both corticotomy and osteotomy are used to make bone fracture for distraction osteogenesis^{5,11,12,14,15,16}. However, a detailed analysis of the bone regeneration following use of these two different surgical techniques is not yet available. In a goat model we have observed more bone formation and earlier mineralization when bone marrow integrity was preserved before mandibular distraction. In this regard, it supports one of the principles for distraction osteogenesis developed by Ilizarov^{6,7}, which emphasized the importance of the presence of an intact intramedullary blood circulation during limb lengthening. His studies recommended a careful corticotomy for protecting the bone marrow prior to distraction.

In the present study, the surrounding periosteum at the surgical site was preserved, and the same distraction rate was used to compare the new bone formation following different surgical techniques used. Our results demonstrate that the corticotomy distraction appears to show more mature regenerated bone than the osteotomy distraction after mandibular lengthening. Additionally, we have found a statistically significant higher Ca/P ratio in the corticotomy side than in the osteotomy side. This implies that the corticotomy distraction was able to induce earlier mineralization. In the process of distraction osteogenesis, mechanical stretch stimulates the osteoprogenitor cells to differentiate into osteoblasts that have the ability to form new bone. Because the osteoprogenitor cells exist not only in the periosteum, but also in the bone marrow, corticotomy for keeping the integrity of the endosteum and bone marrow would have positive and additive effects on bone regeneration and remodelling after osteodistraction. Moreover, corticotomy has the advantage of protecting the capillary network of the inferior alveolar neurovascular bundle, which may contribute to the early angiogenesis and subsequent osteogenesis within the distraction gap. In contrast, the bone marrow including the medullary vessels that was damaged by osteotomy needs time to repair, which may delay the course of new bone formation in mandibular distraction.

The mode of bone regeneration after distraction osteogenesis remains controversial. Kojimoto et al.¹⁰ using osteotomy distraction, reported that the new bone was formed by endochondral ossification. Conversely, Karp et al.⁹ found a predominantly intramembranous process in mandibular distraction osteogenesis after corticotomy. Whereas, other studies showed that the regenerated bone within the distraction gap was formed by both intramembranous and endochondral ossification^{5,6,8,11}. Ilizarov^{6,7} reported that the presence of cartilage is the result of mechanical instability of the bone segment and suggested that rigid fixation leads to direct intramembranous ossification. In our study, a strong rigidity was obtained in all animals; however, a few cartilage islands were seen in osteotomy sites at 2 weeks postdistraction. It is possible that the osteotomy may result in more cartilage islands at an earlier stage than that period after distraction. Although the exact mechanism of cartilage formation during distraction osteogenesis is unclear, the low oxygen tension in the

tissue resulting from a lack of blood supply may be a causative factor in the formation of cartilage islands at the osteotomy sites².

Many experimental and clinical studies demonstrate that mandibular bone can be regenerated by controlled distraction. Distraction rate plays an important role in bone regeneration. Stewart et al.¹³ observed that rapid distraction resulted in a greater incidence of non-union within 4 weeks' fixation after mandibular lengthening. Troulis et al.¹⁶ also found that porcine mandible distracted at a very high rate (4 mm/day) showed a vacant 7 mm gap size (no evidence of fibrous and osseous) after 24-day fixation by the distractor. Therefore, we hypothesized that a 10-mm gap in this animal model created by osteotomy with acute movement could not heal on its own without slow distraction at the sacrifice time.

Despite a number of studies^{3,8,10} that showed that osteotomy does not have an adverse effect on the final outcome of distraction osteogenesis, the present data suggests that corticotomy is beneficial in obtaining optimal bone regeneration after mandibular lengthening. Distraction osteogenesis usually takes a long time, which may result in many problems. In order to shorten the treatment period, several therapies such as electrical stimulation⁵, osteoblast-like cell transplantation¹⁷, and growth factor infusion¹⁴ have been used to promote new bone formation and facilitate the consolidation. The use of corticotomy may be another way to induce earlier bone regeneration and better remodelling for distraction osteogenesis. When performing corticotomy in clinics, it is noteworthy that mandibular cortex bone of the desired distraction region should be cut circumferentially; incomplete fracturing of the lingual cortex may cause some problems in mandibular osteodistraction¹⁵.

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Fig. 1. Mandibular radiographs at sacrifice, showing the differences in radiodensity between the corticotomy (CO) and the osteotomy (OS) sides. Note greater formation of periosteal callus (arrows) on the osteotomy sites at 4 and 8 weeks' postdistraction. (A) 2 weeks. (B) 4 weeks. (C) 8 weeks.

Fig. 2. Histological photomicrographs of the regenerate bone in the distraction gap. (A) Corticotomy—2 weeks (HE×40). (B) Osteotomy—2 weeks (HE×40). (C) Corticotomy—4 weeks (HE×40). (D) Osteotomy—4 weeks (HE×40). (E) Corticotomy—8 weeks (HE×100), showing that mature lamellar bone and fatty marrow filled the newly reformed medullary cavity.

Fig. 3. SEM photomicrographs of regenerate bone in the centre of the distraction gap. (A) Corticotomy—2 weeks (original magnification $\times 50$). (B) Osteotomy—2 weeks (original magnification $\times 50$). (C) Corticotomy—4 weeks (original magnification $\times 200$). (D) Osteotomy—4 weeks (original magnification $\times 200$). (E) Corticotomy—8 weeks (original magnification $\times 200$). (F) Osteotomy—8 weeks (original magnification $\times 50$). Note an interface and some differences in density between the new bone (NB) and the original bone (OB).

Table 1

Grading of bone regeneration in the distraction gap. Modified from Alberius et al. 1990

Variable	Status	Score
Bone regeneration	No	0
	Small amount	1
	Present in moderate amounts	2
	Profuse amount	3
	Bridging-like appearance	4
Bone marrow	No	0
	Beginning to appear	1
	Present in moderate amounts	2
	Colonization by red marrow or fat detectable throughout the distraction gap	3

Table 2

Results of grading of bone regeneration in the corticotomy and osteotomy sides

Type of surgery	Postdistraction (weeks)	No.	Grading scores	
			Bone regeneration mean (range)	Colonization of bone marrow mean (range)
Corticotomy	2	6	2.3 (1–3)	0.6 (0–1)
	4	6	3.3 (3–4)	1.7 (1–2)
	8	6	3.9 (3–4)	2.7 (2–3)
Osteotomy	2	6	1.7 (1–2)	0.3 (0–1)
	4	6	2.5 (2–3)	1.2 (0–2)
	8	6	3.3 (3–4)	2.1 (1–3)

Table 3

Presentation of ratio between regeneration of the corticotomy side in relation to the osteotomy side

Postdistraction (weeks)	No.	Mean ratio of grading scores (corticotomy/ osteotomy)
2	6	1.45
4	6	1.35
8	6	1.22

Table 4

Ca/P ratios of regenerate bone for both corticotomy and osteotomy (mean $\pm$ SD, $n=30$ units)

	2 weeks	4 weeks	8 weeks	Normal bone
Corticotomy	0.85 $\pm$ 0.03	1.35 $\pm$ 0.03	1.89 $\pm$ 0.03	1.96 $\pm$ 0.02
Osteotomy	0.63 $\pm$ 0.04	1.18 $\pm$ 0.02	1.74 $\pm$ 0.03	

Note: Measuring 5 units for each specimen.