

Gonial angle changes after bilateral unidirectional mandibular distraction in sheep

M. Helmy*, J. Lammens**, A. Struelens***, A. Verdonck*, G. Willems*, J. Schoenaers*** and C. Carels*

*Departments of Orthodontics, **Orthopedics, and ***Oral Pathology and Maxillo-Facial Surgery, University Hospitals of the Katholieke Universiteit Leuven, Belgium

SUMMARY It was the aim of this study to investigate radiologically the distraction site in the gonial angle area after three different protocols of unidirectional mandibular distraction in sheep. Bilateral mandibular distraction was performed in nine sheep, and one other sheep served as a sham-operated control. In the nine experimental sheep, three different distraction protocols were used. In three sheep, an oblique corticotomy line was applied and the distractors were positioned perpendicular to the corticotomy line. In three other sheep, a horizontal corticotomy line was applied and the distractors were also positioned perpendicular to this corticotomy line. In the remaining three sheep, again, a horizontal corticotomy was performed, but with an angular positioning of the distractors relative to this corticotomy line. Distraction of 20 mm was performed over 20 days at a rate of 1 mm per day. After 3 weeks of retention the sheep were sacrificed, the mandibles were dissected and hemisectioned, and standardized hemimandibular contact radiographs were made of the specimens. The distracted gaps were traced from the radiograph and the gonial angle was measured. The displacements of the distracted parts were measured, the gonial angles were determined, and the values were compared with four additional control non-distracted sheep mandibles.

The results show that there was a very large variability in the distracted gaps as well as in the gonial angle changes after distraction, and it was not possible to recognize any of the three different distraction protocols radiographically after distraction. Although performed under standardized conditions it is difficult to reproduce intended mandibular corticotomy lines in sheep.

Introduction

Distraction osteogenesis is a dynamic bone-generating process, which is elicited by progressive separating of two bony parts. This is in contrast with corrective osteotomies, where the calculated outcome position is technically instituted and bone gaps are bridged in static conditions. The results of Ilizarov's technique in the extremities, the surgical implications of the mobilization of facial bones by means of osteotomies, and the use of autologous bone grafts in children have been reasons for the application of the gradual bone distraction method in the cranio-maxillo-facial area (Snyder *et al.*, 1973).

Rachmiel *et al.* (1993) used distraction osteogenesis for midface advancement of five young adult sheep aged 10–12 months. They concluded that the combination of osteotomy and gradual distraction offers a controlled correction of the deformity, obviating the need for bone grafting (Rachmiel *et al.*, 1995).

Havlik and Bartlett (1994) used mandibular distraction for lengthening severely hypoplastic human mandibles. They reported that it offered solutions to clinical problems, such as changing the shape of the bone by augmentation at particular anatomical locations, which were difficult to solve by other means.

Distraction osteogenesis was successfully used by McCarthy (1994) in the reconstruction of the mandible in unilateral craniofacial microsomia patients. His results showed that mandibular distraction was an effective and powerful reconstructive surgical technique and could be safely performed to reconstruct and change the steep gonial angle. That author also claimed that there were a concomitant expansion of the functional envelope and soft tissues, and a multidimensional expansion of the lower jaw with minimal evidence of relapse.

Pensler *et al.* (1995) studied the skeletal distraction of hypoplastic mandibles in six young adult patients, and reported that gradual skeletal distraction appeared to offer significant advantages over classic orthognathic treatment for mandibular micrognathia in this group of patients and resulted in a decrease in the steep gonial angle.

Polley *et al.* (1996) used simultaneous distraction osteogenesis and microsurgical reconstruction for treatment of facial asymmetry. Their results showed that distraction osteogenesis was successful in achieving bone lengthening and reconstruction.

Stucki-McCormick (1997), using transport distraction osteogenesis to reconstruct the mandibular condyle in two patients, showed that after distraction the bone was

found to have remodelled, inducing a new cortical layer on the articular surface. Additionally, a pseudodisc was generated as a result of the transport distraction.

The skeletal and dental positional changes and histomorphology of the distraction that occurred after simultaneous widening and bilateral lengthening of the mandible in baboons were studied and analysed by Bell *et al.* (1999). They found that there were positional changes of the canines and incisor apices due to skeletal movement. Their results also support the clinical use of distraction to selectively widen and lengthen the mandible.

It is clear from the literature that mandibular distraction can influence the shape of the mandible. Consequently, this method could be used to model the gonial angle by applying different directions of corticotomy lines and selective application of distractors. The aim of this study was to evaluate the changes in the gonial angle after bilateral unidirectional mandibular distraction in three groups of experimental sheep.

Materials and methods

The distractor

The distractor used in the experiments is a stable apparatus (Figure 1). It is a unidirectional distractor, which rigidly connects the distractor pins and which is capable of distracting the mandibular segments even in adult sheep who exert strong grinding forces laterally and vertically during chewing. A displacement of 1 mm with the distractor was achieved by a 360 degree turn of

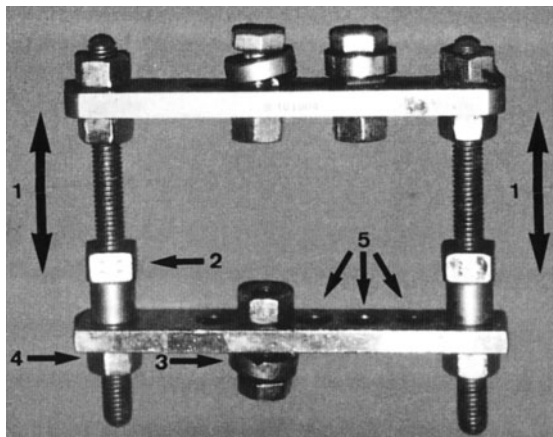


Figure 1 Photograph of the distractor used in the experiments: it is a stable device, rigidly interconnecting the distractor pins; (1) the direction of activation of the distractor on the threaded transfer rod positioned perpendicular to the axis of distraction were mounted in the most lateral part of the distractor frame; (2) threaded transport bolts to calibrate the amount of distractor activation; (3) ring with slot where the pins are inserted and fixed; (4) locking bolts must be set free during activation and tightened after transport; (5) holes in the metal frame of the distractor where the distance between Steinman-like pins can be controlled.

the two transport screws. These transport bolts are locked or freed after the two locking bolts are set free. Because it is a rigid box, it was expected that no deviation from the direction of distraction would be possible.

The experimental animals

Ten sheep were provided and cared for by the Center for Animal Research of the Katholieke Universiteit Leuven. Approval for the experimental animal protocol was received from the Ethics Committee of the University. Three experimental groups each containing three sheep were identified, in each of which combinations of the direction of the distraction vector and the orientation of the corticotomy line were defined (Figures 2–4). One sham-operated sheep served as a control.

The control sheep

The control sheep underwent the same procedure as those in the experimental groups except that the distractors were not activated.

Mandibular distraction type A

In distraction protocol A (Figure 2), an oblique corticotomy line was used and the direction of the distraction was perpendicular to the corticotomy line. The pins were inserted parallel to the corticotomy line. The main distraction vector was 45 degrees to the vertical axis of the ascending ramus. The corticotomy was widened by a force perpendicular to its orientation.

Mandibular distraction type B

In distraction protocol B (Figure 3), the horizontal corticotomy line extended from the inner mandibular angle to a point on the posterior border of the ramus, which renders this line nearly parallel to the lower border of the mandibular body. The direction of the distraction in this group was also perpendicular to the

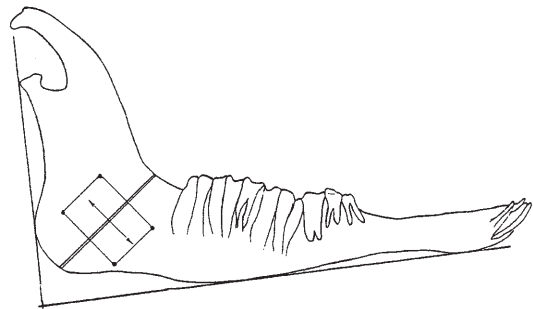


Figure 2 Tracing of a sheep mandible illustrating distraction type A, applied in sheep 2–4, with an oblique corticotomy line and with the distractor placed perpendicular to the corticotomy line.

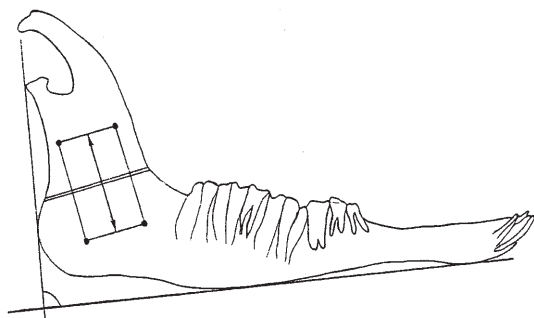


Figure 3 Tracing of a sheep mandible illustrating distraction protocol type B, applied to sheep 5–7 with a horizontal corticotomy line in the ramus and with the distractor placed perpendicular to the corticotomy line.

corticotomy lines on both sides of the mandible. The pins of the proximal and distal sides of the distractor were placed parallel to the corticotomy line. The main distraction vector was parallel to the vertical axis of the ascending mandibular ramus. The corticotomy was widened by a force perpendicular to its orientation.

Mandibular distraction type C

In distraction protocol C (Figure 4), the horizontal corticotomy line was the same as in protocol B but the position of the distractors was oblique to the corticotomy line, namely at a 45 degree anterior inclination. The main distraction vector was 45 degrees oblique to the vertical axis of the ascending ramus. The corticotomy was widened by a force under 45 degrees obliquely orientated to the line.

Preparation of the sheep

All animals received care in compliance with the Principles of Laboratory Animal Care formulated by the National Society for Medical Research and the Guide for the Care and Use of Laboratory Animals

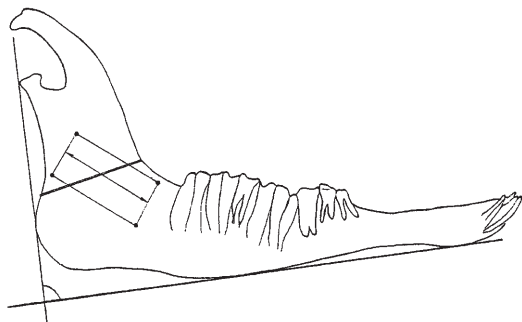


Figure 4 Tracing of a sheep mandible illustrating distraction protocol type C, applied to sheep 8–10 with a horizontal corticotomy line in the mandibular ramus and with the distractor placed at 45 degrees to the corticotomy line.

prepared by the National Academy of Sciences and published by the National Institutes of Health. Because sheep are ruminants, they were fasted for 2 days before the operation. In that way, aspiration of the food from the stomach was prevented.

Anaesthesia

Induction was achieved by intramuscular injection of Ketalar® (10–20 mg/kg) (Parke Davis, Zaventem, Belgium). After the sheep were asleep, a mask with initially 100 per cent O₂ was applied. At this stage, the sheep were positioned on the operation table. The anaesthetic procedure consisted of transoral intubation and halothane administration increasing from 0 to 4 per cent. A long endotracheal canula was placed between the jaws of the sheep through a hole in a wooden block. After intubation, the sheep were ventilated with 50 per cent O₂ and 50 per cent N₂O. Ventilation was adjusted to maintain arterial blood gases and pH within the physiological range. An arterial line was inserted in a conchal vessel in order to continuously monitor blood pressure and to take samples for blood gas analysis. A venous line was placed in a peripheral limb vein for continuous infusion with 0.9 per cent NaCl. Continuous electrocardiographic monitoring was carried out.

Surgery

Before starting the operation, the left and right sides of the head of the sheep were shaved, prepared with iodine antiseptic solution, and draped. In order to preserve a rigid bone structure at the time of pin insertion, final release of the bone segments was postponed until pin placement had taken place. In the initial stage of the surgery, the positioning and orientation of the corticotomy line were determined. With the sheep in lateral decubitus, the line of the skin incision was first drawn with a sterile pen corresponding to the area of the inferior and posterior borders of the mandible at the angular region. The intra-oral inner mandibular angle was located and a corresponding line was drawn on the skin. The line of the intended corticotomy was drawn on the skin between the previous two lines making an appropriate angle with the posterior border of the ascending ramus. Four points were also drawn on the skin, two on both sides of the corticotomy line (Figure 5a). These points represented the location of the four pins that gave support to the distractor. The pins were 11 cm in length with a diameter of 2 mm (Citieffe®, Italy). These pins have sharp and tapered ends followed by a threaded length of 2 cm that holds in the bone, then a smooth round part is followed by a rectangular end, which is fixed to the distractor. The correct location determines the orientation of the distractors. This again determines the vector of the distraction, which was

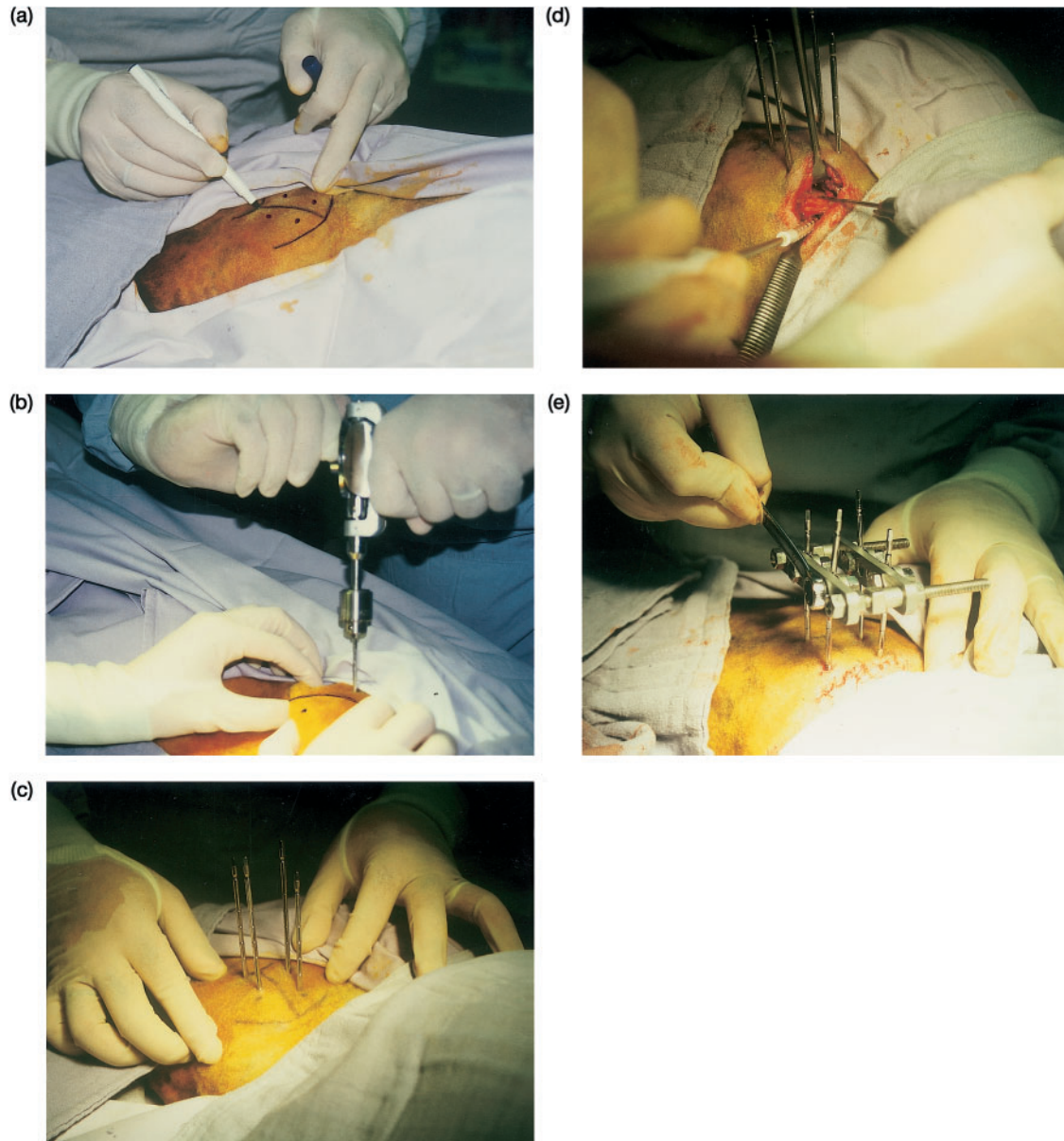


Figure 5 (a) A line was drawn on the skin corresponding to the area of the inferior and posterior borders of the mandible at the angular region and the intra-oral mandibular angle. The line of intended corticotomy was also drawn on the skin between the two previous lines making an appropriate angle with the posterior border of the ascending ramus. Four points were also marked on the skin (two on both sides of the corticotomy line) corresponding to the location of the pins. (b) The first pin, mounted on a hand drill was forced into the skin through a small incision until it came into contact with the bone. (c) The four pins were fixed in the mandibular bone. (d) The medial retraction of the digastric and the deeper lying mylohyoid muscle allowed exposure to the lingual side of the mandible. Then the drilling operation started on the posterior margin of the buccal cortex and was continued as far as visibility allowed. (e) After closing the incision the distractors were mounted and fixed to the four pins.

crucial for the study. With a number 15 blade, an incision point was made in the skin. The first pin, mounted on a hand drill, was forced into the skin through this small incision until it came into contact with the bone (Figure 5b). The pin was then drilled into the mandibular bone. After the four pins were fixed in the mandibular bone (Figure 5c), the distractor was attached to these pins to check the location and orientation of the

distractor. The distractor was then removed and the skin incised.

An extra-oral curvilinear incision in the retromandibular region was performed in order to approach the ascending ramus (Risdon type incision). The skin and the platysma muscle were incised to reveal the superficial portion of the masseter muscle lying laterally and the digastric muscle lying ventromedially over the body of

the mandible. Careful anterior reflection of the parotid gland was sometimes necessary in order to avoid a salivary fistula, which might compromise wound healing. An incision was made in the intermuscular septum between the masseter and the digastric muscle. The regional vessels were ligated. Lateral retraction of the masseter muscle and subperiosteal elevation of part of its insertion allowed exposure of the lateral side of the mandibular body and ramus. The medial retraction of the digastric and the deeper lying mylohyoid muscle allowed exposure of the lingual side of the mandible. The corticotomy line then started from the infero-posterior border of the mandible towards the retromolar pad on the inside, using a Lindemann surgical bur. The periosteal envelope was elevated from the inner and outer cortical surfaces. The drilling operation started on the posterior margin of the buccal cortex and was continued as far as visibility allowed (Figure 5d). On the lingual side of the ramus, the bone surgery was in line with the outer cortical one. The chiselling work of the inner anterior cortex of the mandibular ramus took place without visual control. At the end of this procedure, both bone fragments could be independently moved. The enveloping periosteal layers were stretched in order to ascertain primary mobility in the distraction site. After the corticotomy line was achieved, 3 cc. of Xylocaine® (Astra/Therabel, Brussels, Belgium) 2 per cent (1/80,000 adrenaline) was infiltrated at the site in order to prevent post-operative pain.

When closing the wounds in a layered fashion, Spitalen® (Bencard) (Neomycine) was powdered into the wound and the periosteal layer was closed with Vicryl 3.0. The parotid gland capsule was repositioned and sutured with Vicryl 4.0. The skin was closed using Ethilon® 3.0. Everting interrupted stitches were applied. As one side was finished, the same procedure was subsequently performed on the other side. Care was taken to avoid saliva leakage and contamination of the wounds. After closing the incision on both sides, the distractors were mounted and fixed at each side to the four pins.

After checking whether the orientation of the devices was correct, the fixation screws were locked (Figure 5e).

The distraction and stabilization phases

The activation of the distractors started after a latency period of 5 days. The amount of distraction was set at 1 mm in one session per day without interruption. A total distraction of 20 mm was applied to each animal except to the control sheep. A complete turn of the right and left activation screws of each distractor was carried out daily. This complete turn equalled 1 mm of distraction. On each side of the activation screw, a number of points for demarcation were present. A wrench was used to loosen the activation screws, a complete turn was carried out by hand, and then the locking screws

were retightened. The distractors remained in place as retainers during the 4-week stabilization after the distraction period of 20 days. At the end of the retention period, the sheep were sacrificed using a high dose intravenous Nembutal® (Abbott, Ottignies, Belgium) injection. The distractors were then removed and the mandibles were dissected and preserved by immediate placement in liquid nitrogen for 1 minute, and then removed and preserved at -80°C.

Hemimandibular contact radiographs after sacrifice

Conventional radiographs of the dissected and hemisected hemimandibular specimens were taken in a standardized set up (Figure 6). Agfa® (Agfa Gevaert, Antwerp, Belgium) X-ray film was placed parallel with the hemimandibles. These radiographs allowed avoidance of superimposition of the hardware; moreover, the object-film distance could be fixed and parallel object-film position could be achieved.

Feeding and maintenance

During the experimental period the sheep were fed normal food. Some sheep started eating normal food from the first post-operative day until sacrifice. Others, however, had problems that could be attributed to the surgical trauma or to the distraction procedure itself and started eating later.

Determination of normal gonial angle in sheep

Four dissected non-operated normal mandibles of sheep were used as controls to determine the normal gonial angles, which ranged from 89 to 90.5 degrees.

Results

On the traced hemimandibular radiographs, the gonial angles were evaluated for the different protocols. The results are given in Table 1. (A) shows the measurements of the post-sacrifice distraction angulation, where '+'



Figure 6 Conventional radiographs of the dissected and hemisected hemimandibular specimens were taken in a standardized set up.

Table 1 (A) Measurements of the distraction post-sacrifice mandibular plane angulation: + indicates a posterior rotation of the ventral part of the mandible; – indicates an anterior rotation of the ventral part of the mandible; 0 degrees indicates a translation of both distracted parts; (B) measurements of the post-sacrifice gonial angles of the left and/or right hemimandibles of all experimental sheep and of the four mandibular control specimens.

Sheep	A		B	
	Right side (degrees)	Left side (degrees)	Right gonial angle (degrees)	Left gonial angle (degrees)
1	Sham	Sham	91	89
2	+6	0	73	77
3	–6	–7	92	91
4	+11	+24	71	78
5	Defect	+8	Defect	77
6	–27	–26.5	107	108.5
7	+17	+5	76	61
8	+8.5	/	84.5	82
9	+4	+9	81	72
10	+14	+16	66	76
11	Control	Control	89	89.5
12	Control	Control	90	90
13	Control	Control	90	90
14	Control	Control	90.5	90

represents an anterior (counterclockwise) rotation of the ventral part of the mandible and ‘–’ a posterior (clockwise) rotation of the ventral part of the mandible, with 0 degrees there is a translation of both distracted parts. (B) shows measurements of the post-sacrifice gonial angles of the left and/or right hemimandibles of all experimental sheep and of the four mandibular control specimens. The mean gonial angle in the control sheep was 90 degrees and the variation was small (sheep 11–14). In sheep number 2, the post-sacrifice angulation ranged from 0 to +6 degrees, the difference in the gonial angle being –13 degrees (left) and –17 degrees (right). In sheep 3, the post-sacrifice mandibular plane angulation was –6 and –7 degrees, the difference in the gonial angle being +1 degrees (left) and +2 degrees (right), respectively.

From the tracing of the distracted mandibles, the different protocols could not be recognized *post factum*. The gonial angle was increased in sheep 3 and 6, whereas it was decreased by distraction osteogenesis in all the other sheep. The mandibles of sheep 2, 4, 5, 7, 8, 9, and 10 rotated in a posterior direction, whereas those of sheep 3 and 6 rotated in an anterior direction; this was random and did not correlate with the intended distraction and the direction of corticotomy.

Discussion

In this study, post-distraction mandibular gonial angles were evaluated after distraction with different orientation of the corticotomy line and distraction vector. The results show that bone lengthening by distraction osteogenesis does indeed have a direct effect on the

anatomy of the mandible, especially in the region of the mandibular angle. The left–right asymmetries in the post-distraction gonial angle are due to uneven distraction between the right and left sides. An increase in the gonial angle means that the distraction distance between the two bone fragments at the inner mandibular angle is much larger than at the outer mandibular angle. This results in a posterior (clockwise) rotation of the ventral part of the mandible mesial to the corticotomy line. Due to opening muscle attachments, the anterior part of the mandible mesial to the corticotomy line can easily establish a posterior (clockwise) rotation. In the other seven sheep, the mandible rotated anteriorly, which could be explained by the position of the corticotomy line relative to the attachment of the elevator muscles (such as the masseter muscle); if the corticotomy is located anterior to the masseter attachment a posterior rotation is expected; if it is located posterior to the attachment of the masseter muscle, then a clear anterior rotation of the mandibular body is expected.

The effect of intentionally varying the site and orientation of both corticotomy line and distractor was not clear from the distracted hemimandibles. In one sheep that underwent protocol A the gonial angle had increased, whereas the gonial angle of the other two sheep had decreased. This could mean either that there are other factors in addition to the site and orientation of both corticotomy line and distractor that control the direction of rotation of the mandible, or that the protocol was not well enough controlled during the operation. Of course other factors could contribute. In future studies, the placement of the distractors should be carried out in a more controlled way and under more standardized

conditions. One of the 'other factors' could be the muscular attachment as mentioned previously, but also the anatomical relationship and force of the occlusion could play a role since sheep demonstrate strong lateral movements during chewing. This might influence the direction of the distraction and, consequently, the value of the gonial angle. The thickness and stability of the bone where the pins are fixed may play a minor role. Another factor is the completeness of the corticotomy: incomplete corticotomy resists the activation of the distractor at a certain point, which leads to variation in the distraction distance, consequently affecting the value of the gonial angle (Schwartzman and Schwartzman, 1992). As mentioned by Ilizarov (1971), the preservation of the periosteum can affect the direction of distraction and the blood flow can affect the outcome of distraction (Aronson, 1994). Lastly, traumatization and nerve injury can also affect, to some extent, the outcome of the distraction (Block *et al.*, 1993).

The result of the present research shows variability in the values of the gonial angles in spite of the fact that the majority of sheep had a decreased gonial angle after distraction. These findings are in agreement with those of McCarthy (1994) who used distraction osteogenesis in the treatment of unilateral craniofacial microsomia, which resulted in a decrease of the steep gonial angle. These results mean that bone lengthening the mandibular ramus in sheep might be associated with an anterior rotation of the mandible, and, consequently, if an anterior open bite existed it would be reduced. As it was not possible in this study to recognize thoroughly the three different distraction protocols in the radiographs after distraction, more careful operative planning should be applied in future experiments in order to direct the distraction as planned.

Conclusions

1. There was a large variability in distracted gaps as well as in the gonial angle changes after distraction.
2. It was not possible to recognize any of the three different distraction protocols in the radiographs after distraction.
3. It was possible to change the gonial angle by distraction osteogenesis.

Address for correspondence

Professor C. Carels
Department of Orthodontics
Catholic University of Leuven
Kapucijnenvoer 7
B-3000 Leuven
Belgium

Acknowledgements

Our sincere thanks go to Prof. Dr M. Bossuyt, Department of Maxillo-Facial Surgery, for his useful advice to the staff of the Centre for Animal Research. We also are indebted to several staff members in different Departments of the University Hospital of the Katholieke Universiteit Leuven: Prof. Dr Hermans from the Department of Radiology, Prof. Dr W. Flameng, and Dr R. Racz from the Centre for Experimental Surgery and Anaesthesiology. These experiments were sponsored in part by the Fonds voor Wetenschappelijk Onderzoek (FWO, Belgium) and by Synthes NV, Brussels, Belgium.

References

- Aronson J 1994 Temporal and spatial increases in blood flow during distraction osteogenesis. *Clinical Orthopaedic and Related Research* 301: 124–131
- Bell W H, Gonzalez M, Samchukov M L, Guerrero C A 1999 Intraoral widening and lengthening of the mandible in baboons by distraction osteogenesis. *Journal of Oral and Maxillofacial Surgery* 57: 548–562
- Block M S, Daire J, Stover J, Matthews M 1993 Changes in the inferior alveolar nerve following mandibular lengthening in the dog using distraction osteogenesis. *Journal of Oral and Maxillofacial Surgery* 51: 652–660
- Havlik R J, Bartlett S P 1994 Mandibular distraction lengthening in the severely hypoplastic mandible: a problematic case with tongue aplasia. *Journal of Craniofacial Surgery* 5: 311–312
- Ilizarov G A 1971 Basic principles of transosseous compression and distraction osteogenesis. *Ortopediia Traumatologiya i Protezirovaniye* 32: 7–15
- McCarthy J G 1994 The role of distraction osteogenesis in the reconstruction of the mandible in unilateral craniofacial microsomia. *Clinics in Plastic Surgery* 21: 625–631
- Pensler J M, Goldberg D P, Lindell B, Carroll N C 1995 Skeletal distraction of the hypoplastic mandible. *Annals of Plastic Surgery* 34: 130–136
- Polley J W, Breckler G L, Ramasastry S, Figueroa A A, Cohen M 1996 Simultaneous distraction osteogenesis and microsurgical reconstruction for facial asymmetry. *Journal of Craniofacial Surgery* 7: 469–472
- Rachmiel A *et al.* 1993 Midface advancement by gradual distraction. *British Journal of Plastic Surgery* 46: 201–207
- Rachmiel A, Levy M, Laufer D 1995 Lengthening of the mandible by distraction osteogenesis: Report of cases. *Journal of Oral and Maxillofacial Surgery* 53: 838–846
- Schwartzman V, Schwartzman R 1992 Corticotomy. *Clinical Orthopedics and Related Research* 280: 37–47
- Snyder C C, Levine G A, Swanson H M, Brown Jr. E Z 1973 Mandibular lengthening by gradual distraction. Preliminary report. *Plastic and Reconstructive Surgery* 51: 506–508
- Stucki-McCormick S U 1997 Reconstruction of the mandibular condyle using transport distraction osteogenesis. *Journal of Craniofacial Surgery* 8: 48–52

Copyright of European Journal of Orthodontics is the property of Oxford University Press / UK and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.