

# Evaluating Loading Deflection of Distraction Osteogenic Rib in a Rabbit Model

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**Background:** The treatment of patients with partially atrophic rib and rib defects requires an ideal arc of the rib that has adequate bone length and width. To design and assemble a distraction device with a strain gauge, we need to establish an animal model for testing it during rib distraction osteogenesis.

**Methods:** Osteotomies were performed at the same position in the fifth rib in 8 rabbits. Customized distraction devices attached to strain gauges were used to distract the ribs. After a month of distraction and consolidation, loading deflection gauges were used, and specimens were examined histologically to record bone formation.

**Results:** Distraction osteogenesis was carried out successfully in all rabbits when the device used to distract the rib up to 4 cm.

**Conclusions:** The device can be used for strain testing during rib distraction osteogenesis performed in a rabbit model. There was no significant difference in the loading deflection gauges of the bone between osteogenic and contralateral ribs. This animal model of costal distraction osteogenesis is successful. (*Plast Reconstr Surg Glob Open* 2016;4:e1008; doi: 10.1097/GOX.0000000000001008; Published online 5 October 2016.)

Distraction osteogenesis is the process by which bone is lengthened, by distracting at least 2 segments and allowing the natural healing process of bone to “fill in” the space between the segments. It was first used in limb lengthening by Codivilla<sup>1</sup> in 1905. In 1955, Ilizarov<sup>2,3</sup> formulated the Ilizarov principle, and much research has been done since then; later, the use of this technique in canine mandible was first reported by Snyder et al<sup>4</sup> in 1973. In 1992, McCarthy et al<sup>5</sup> reported the first clinical case of mandibular lengthening by gradual distraction using an extraoral device. Since then, distraction osteogenesis has become increasingly useful for the treatment of congenital and acquired craniofacial skeletal anomalies and other bone defects.

Distraction osteogenesis is based on the law of tension-stress. The stress caused by distraction can stimulate the regeneration of living tissues. According to Wolff’s hy-

pothesis<sup>6</sup> that the length, shape, and volume of bone tissues will change if the strain applied on them is altered, the bone tissue at the gap formed by bone distraction will change gradually. However, the most acceptable theory about bone modeling and remodeling was developed by Frost, who proposed thresholds at which bone formation was activated.<sup>7,8</sup> When local mechanical strains exceed certain boundaries, the bone will be modeled in different ways. The mechanisms of bone formation in distraction osteogenesis of ribs have been not widely studied; Meyer et al<sup>9,10</sup> studied the effects of different strains and tried to find a magnitude of strain for rib formation by focusing on the histological and cellular changes caused by gradual distraction. We have tried to establish an animal model for real-time evaluation of strain in vivo that will record strain during and after rib distraction.

## MATERIALS AND METHODS

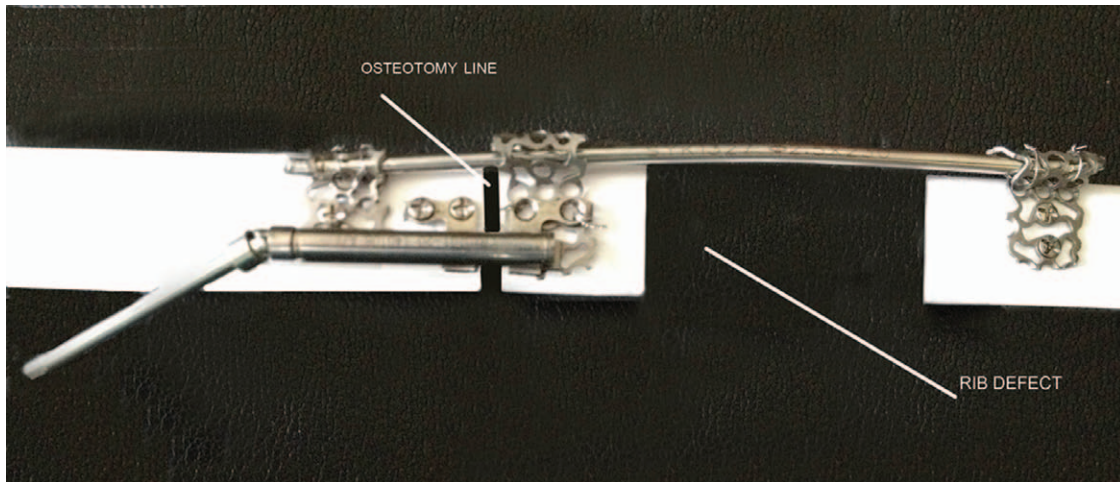
Our customized rib distractors were made from normal mandibular distractors with a screw connection (Fig. 1). The study was carried out on 8 young-adult Chinese white rabbits, which weighed 2500 to 3000g. The protocol and guideline for this study were approved by the Animal Center for Medical Experiment at Nanjing Medical University. The rabbits were prepared and draped in a sterile fashion to expose the fifth rib. Under general anesthesia with 0.1 ml/kg 10% chloral hydrate (product under trial,

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**Fig. 1.** Our customized rib distractor.

made by the Veterinarian Institution of the Commissariat College, Changchun, China) and local application of 1% lignocaine, osteotomies were performed at the junction of the ribs. Penicillin (0.48 g, intramuscularly twice a day) was given for 7 days postoperatively.

A 1cm-length of rib was cut from the stump. The customized distractor was attached with screws (Fig. 1) and activated at a rate of 0.8mm/d postoperatively. At each distraction, the tension at the distracted gap was measured and recorded by a converter. After a 15- or 30-day consolidation (Fig. 2), the osteogenic and contralateral ribs

were removed for examination using loading deflection gauges.

The loading deflection gauges were connected with an analog-to-digital converter (YE2538A, Sinocera Co. Ltd., Shanghai, China) in a half-bridge configuration for evaluation (Fig. 3). The signal from the loading deflection gauges was input to a laptop. The converter was calibrated each time by a standard strain apparatus (Sinocera Co. Ltd.) (Fig. 4). The microtension indicated the percentage of the initial gap for the distracted rib. The data were collected to find out the tension change during the distraction period. As shown in Figure 5, the distracted rib was assembled and loaded with the force.

## RESULTS

The ribs of all rabbits were successfully lengthened by distraction osteogenesis. At the end of the distraction, there was an obvious asymmetrical occlusion and protrusion clearly visible in the distraction gap, with a thin cortical bone. No screws had fallen off. The rabbits

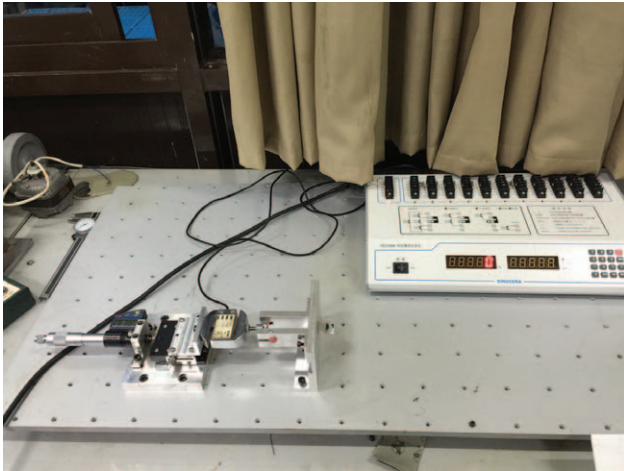


**Fig. 2.** The consolidation period.

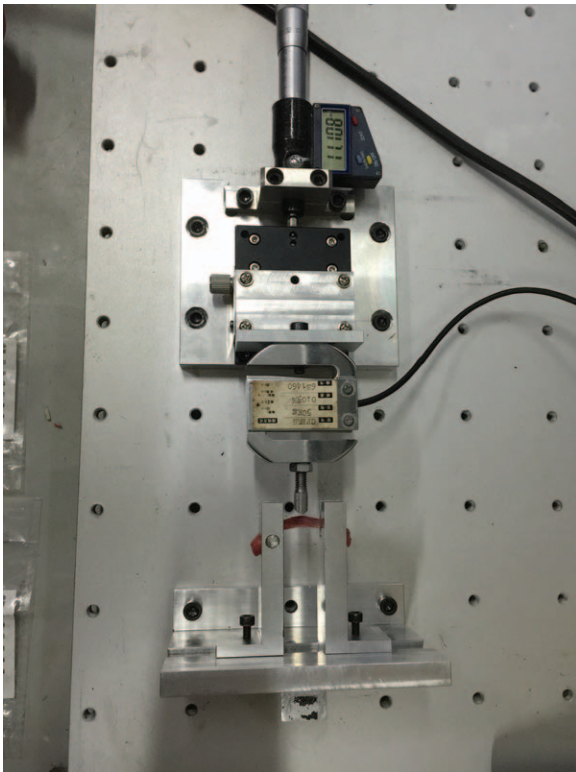


**Fig. 3.** The rib in loading deflection gauges apparatus with unaffected resistance.





**Fig. 4.** The rib in loading deflection gauges apparatus with effected resistance.



**Fig. 5.** The rib assembled and loaded with the force.

that had been tested with the loading deflection gauges had finished the test successfully. The load–deflection curve showed that the shift was significantly different between the 15-day–formed ribs and the contralateral ribs when the force added to 10 N (Fig. 5). These data suggested that the new bone had worse elasticity and tension than the normal rib (Fig. 6). As shown in Figure 7, the loading deflection gauges of the rib that remained for 30 days were consistent with the contralateral rib. Unfortunately, the load–deflection curve showed a cer-

tain difference at the maximum load between the 30-day osteogenic ribs and the contralateral ribs.

## DISCUSSION

Costochondral grafting and distraction are often used in the management of craniofacial microsomia.<sup>7,8</sup> However, these techniques have not been reported for rib congenital diseases. The quality and biomechanical properties of the distracted rib–grafted bone are poorly understood. Many theories<sup>8–10</sup> about the relationship between the force applied to a bone and the formation of a new bone have been documented, which consider that osteoblasts and osteoclasts are produced by the differentiation of mesenchymal cells caused by mechanical load. Frost's theory<sup>9,10</sup> described bone modeling and remodeling. He assumed that the modeling and remodeling of bone were controlled by a feedback system, in which the bone could maintain its structure by local modeling. The lowest effective range of the magnitude of the strain was 1500 to 2500  $\mu\epsilon$ . The bone would be absorbed if the effective strain was lower than 50 to 200  $\mu\epsilon$  or be remodeled if the effective strain was higher than 4000 to 5000  $\mu\epsilon$ . However, Meyer et al<sup>11,12</sup> found that 2000 and 20,000  $\mu\epsilon$  might lead to bridging of an artificial fracture by woven ossification and trabecular bone formation. We found that the 15-day–formed bone had worse elasticity and stress than the normal rib, and the loading deflection gauges of the rib that remained for 30 days were similar to the normal rib. However, there was still a little difference at maximum load test between the 30-day–osteogenic and the contralateral ribs, which suggests that more days must be needed for consolidation, even 3 months in humans.

The junction of the rib and sternum provides a space that avoids friction from the distractor, which means that there is as little influence as possible on the evaluation of the strain. Distraction osteogenesis is easy to achieve because the bone of the rib was thin. The stress on the distraction gap is transferred from the rigid fixed bone to the distractor arm wherein the strain gauge reacted to the strain. The half-bridge configuration of analog-to-digital converter and strain gauge helped us evaluate the change in resistance of the strain gauge, so the strain gauge can show in vivo exactly what strain is being put on the newly forming bony tissue. Therefore, we can obtain the data easily and accurately.

Measurement in the rabbit rib has shown an increase in the trends to change tensions during the distraction process. In the long term, some research shows that the change in the strain ratio of the mandible decreases in a hyperbolic curve.<sup>13</sup> The mechanism of the strain ratio of the rib changing by the stress is still unclear. Generally, with the remodeling of the bone, the strain is less as the strength and stiffness of the bone increases.<sup>14</sup> However, during distraction, strain increased for 2 reasons. First, newly generated tissues in the distraction area, including collagen and fibrous tissues, became stronger, holding back the distraction force. Second, the adaptation of soft tissues around the distracted area prevented the genera-

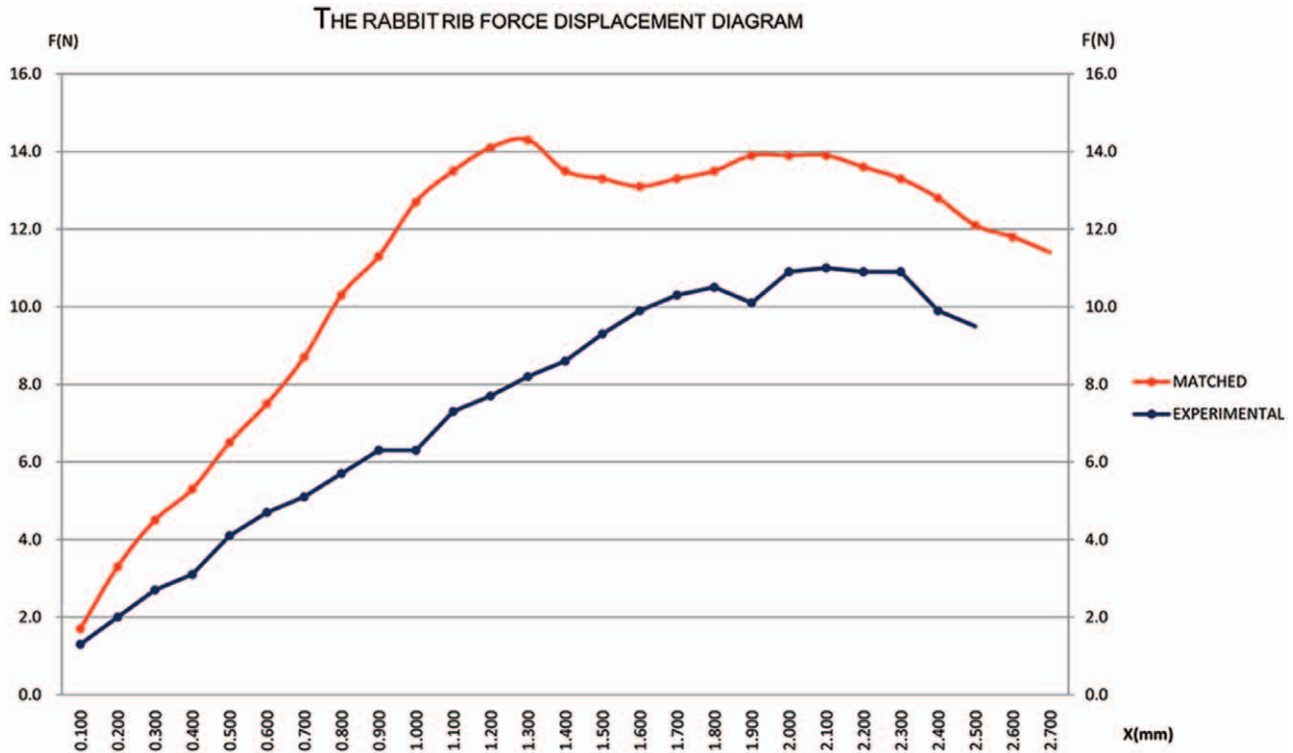


Fig. 6. The load–deflection curve of 15-day–formed and normal ribs.

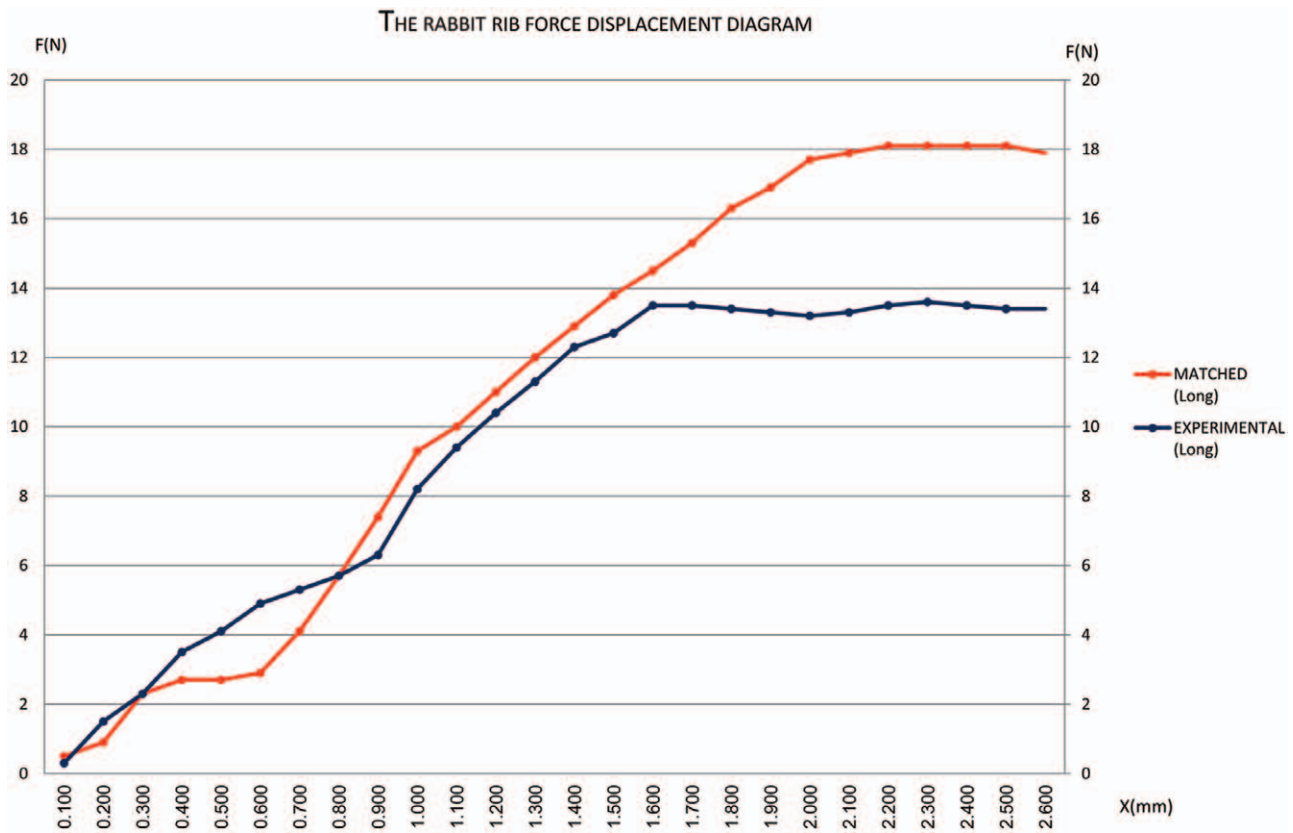


Fig. 7. The load–deflection curve of 30-day–osteogenic and contralateral ribs.

tion of new tissue. When new bone becomes calcified, the force holding it back becomes less, and soft tissues adapt as the strain decreases gradually. The article provided some laboratory databases to describe the relationship between strain and consolidation, which verified that 30-day consolidation is much better.

There are also some unresolved problems in this experiment. One of them is that the distractor must have guide rods, which can produce curved osteogenic ribs. In addition, loading deflection monitoring can be used to compare the bone stress tolerance and the connection intensity between the new bone and normal ribs. However, the strain data from the second group showed that in the short term, the strains were increased by the distraction. As shown in load–deflection curve, stress tolerance of the extended bone is the same as that of the normal ribs; but the connection of the newly formed rib and the normal rib is slightly weak, which suggests that 2 to 3 months of fixed time will be best.

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