CHARACTERIZATION OF BOUNDARY CONDITIONS FOR A FINITE ELEMENT MODEL OF MANDIBULAR DISTRACTION OSTEOGENESIS

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INTRODUCTION

Distraction osteogenesis (DO) is an elegant method used to form bone tissue in vivo. Surgical division of an existing bone and gradual separation of the disconnected bony fronts stimulates the body's natural response to heal fractured bones. As the two halves of the bone are slowly spread apart, new bone is generated from the local substrate yielding anatomical and functional expansion of bone tissue. Full bony bridging between the original cut ends of the bone can be obtained. This method of tissue engineering is rapidly gaining popularity for the treatment of craniofacial defects such as the pediatric mandibular deficiency known as severe micrognathia. Despite common clinical use of the technique, little is known about the various mechanisms that distinguish adaptive healing (bony union) of the distraction defect from a maladaptive response (fibrous union). The mechanical environment may play a role, either through mechanically-induced signaling or as a result of damage. The overall goal of this research program is to evaluate the mechanical environment that leads to an adaptive response compared to that which produces a maladaptive response in a rat mandible model of distraction osteogenesis.

In order to quantify the mechanical environment of the gap tissue that later becomes bone, finite element models of this gap tissue and surrounding bone will be developed for both the adaptive and maladaptive cases. In order to create the finite element models, many parameters must be determined experimentally. Inputs to the finite element model include boundary conditions that are applied to the mineralized bony ends. Therefore, the purpose of this study was to characterize the loads in the fixator in a rat model of distraction osteogenesis. Through the finite element model, the force across the gap, as well as tissue stresses and strains, will be obtained.

METHODS

Eleven male Sprague-Dawley rats were surgically outfitted with a mandibular distraction device (Figure 1). Four strain gages were applied to the posterior cap of the functioning side, two each on the compressive and tensile surfaces. The four strain gages were configured in a full bridge when connected to the strain gage amplifier.

A previous study [1] indicates that an adaptive response is achieved by following the distraction surgery with 3 days of latency, 8.5 days of distraction, and 28 days to allow for the consolidation of the bone. Following this schedule, the mandible was distracted 0.3 mm twice per day (every 12 hours) for an overall distraction of 5.1 mm. Twice per day during distraction, and once per day during consolidation, data was collected via a LabVIEW program at 60 Hz. The animals were allowed free cage activity during data collection, except during distraction in which the animals were minimally restrained by hand. On days of distraction, data was collected for 2 minutes prior to the distraction, during the distraction process, and for 10 minutes post-distraction. During consolidation, data was recorded for a total of 12 minutes. While data was obtained, the activities of each rat (e.g. cleaning, eating, and drinking) were recorded to allow identification of the data collected during each activity. Only the data obtained during the distraction time period, in the 10 minutes post-distraction, are reported here.

Figure 1: Distraction device on rat mandible.

The data files were divided by activity using a LabVIEW VI. One second of data was trimmed from each end of the resulting data sets to account for any inaccuracy in recording activities. The recorded voltages were converted to forces based on dead weight calibration of the strain gauges. The reported analysis focuses only on the following activities during the distraction period: cleaning, grinding its jaws, and sitting still. Other activities (moving, eating, sniffing, and drinking) are not included because too few subsets containing only one of these activities at a time existed for the distraction phase of data collection.

RESULTS

Four rats were excluded from analysis due to complications during data collection or malfunctioning strain gauges post-operatively. Means and standard deviation for each activity within each session from the remaining seven rats were plotted for comparison.

Figure 2 shows the plotted mean force during jaw grinding. The x-axis is the time at which data was obtained, in terms of days after the beginning of distraction. The y-axis is mean force. Multiple points plotted at a single time indicate multiple periods of this activity from the same data acquisition session. The mean values appear to follow a linear trend throughout the distraction period, and range from a compressive load of 4 N to a tensile load of 2 N.

Figure 3 shows a plot of the standard deviation values calculated for each of the jaw grinding subsets. Standard deviations ranged from nearly 0 N to around 0.15 N, with a few outliers appearing as high as 0.42 N.

Similar plots, force magnitudes, and standard deviations are seen for all three analyzed activities, as shown in Table 1.

Activity	Mean Range (N)	Standard Deviation Range (N) (All Points)	Standard Deviation Range (N) (Excluding Largest 3 Outliers)
Jaw Grinding	-4.19–2.08	0.004–0.426	0.004–0.243
Cleaning	-4.16–1.89	0.014–0.562	0.014–0.246
Sitting Still	-4.18–1.78	0.002–0.346	0.002–0.212

Table 1: Forces obtained during each activity.

DISCUSSION

The large variation in force recordings is likely a result of numerous variables involved in the surgical procedure to install the fixator devices. Previous results suggest that the bone does not fuse during the distraction period; however, fusing of the bone could result in increasing loads during the distraction period, as seen in a few of the specimens.

The force applied to the fixator, measured in this study, is a sum of the forces in the gap tissue and forces in the surrounding soft tissues, including muscle. The finite element model, in combination with additional experiments, is required to estimate the forces in the distraction gap tissue.

The purpose of this study was to determine boundary conditions for a finite element model designed to quantify the mechanical environment of the soft tissue in the distraction gap. The results suggest that the maximum mean force in the fixator is between approximately 4 N in compression and 2 N in tension. The standard deviation values ranging from 0.002 to 0.56 N provide values of a varying force to superimpose on the mean. Upcoming data on the period of time the animals are engaged in each activity during an entire day will allow us to estimate the amount of time each force profile is applied through the fixator.

REFERENCES

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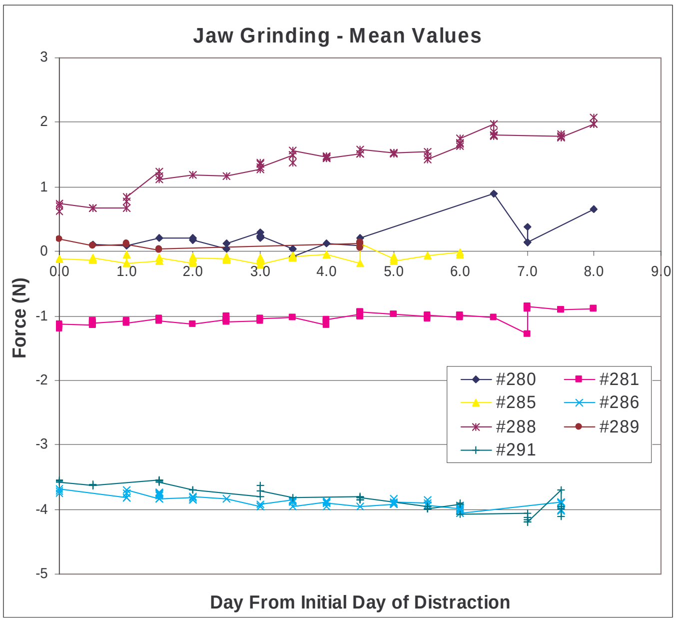

Figure 2: Mean values for jaw grinding activity

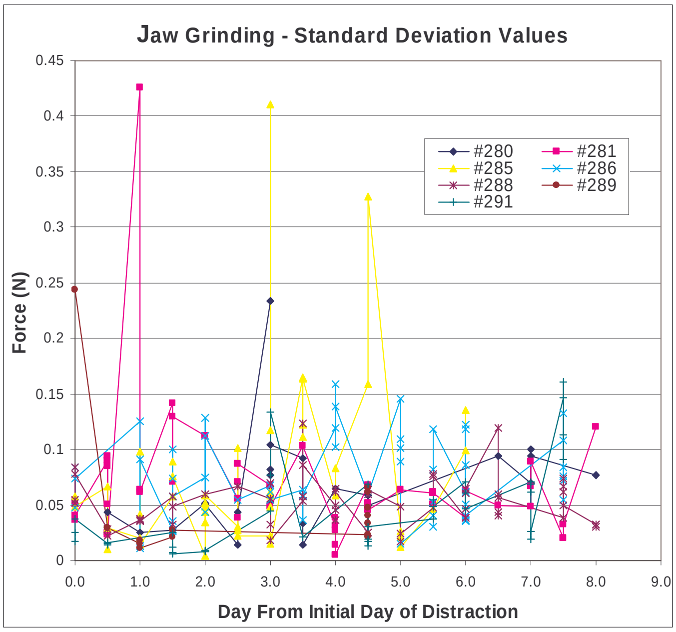

Figure 3: Standard deviation values for jaw grinding activity