INTRODUCTION: Traction injury of the brachial plexus during the birth results in nerve palsy in 1 out of 250 births (1). Although most children with neonatal brachial plexus palsy recover spontaneously, 10-20% have a persistent deficit (2). The most common deficit is weakness of external rotation of the shoulder, leading to an internal rotation contracture, which in turn results in glenohumeral deformity. Not much is known about the nature and mechanism of the glenohumeral deformity in this disorder. The purpose of this study is to evaluate a new surgical model as an animal model of neonatal brachial plexus palsy and to characterize the manifestation of the associated shoulder deformity. We hypothesized that 1) neurotomy of the brachial plexus in neonatal mice would cause bone and joint deformities of the shoulder similar to human neonatal brachial plexus palsy, and 2) deformities would become more severe with longer duration of paralysis.

METHODS: Animal model: Animal protocols were approved by the institutional Animal Studies Committee. Eighteen CD-1 neonatal mice were used. There were two surgical groups: neurotomy and sham. Animals in the neurotomy group (N=15) underwent microsurgical neurotomy (i.e., surgical transection) of the upper trunk brachial plexus in the left shoulder within 24 hours of birth. Mice in the sham group (N=3) underwent surgical exposure of the brachial plexus without resection in the left shoulder within 24 hours of birth. The right shoulders in both groups were left intact to serve as normal contralateral controls. Inhalation anesthesia using isoflurane and aseptic surgical technique were employed throughout the procedure. Mice in the neurotomy group were euthanized 2, 4, and 8 weeks (N=5 per time point) after the procedure, and mice of the Sham group were euthanized at 2 weeks (N=3). Joint range of motion: After euthanasia, mice were placed on an X-ray film in the supine position. Forepaws were fixed with both shoulders fully abducted and both elbows fully extended. Radiographs were taken and digitized. In order to determine shoulder adduction contracture, maximal glenohumeral abduction angle was measured using Image J. In order to determine elbow extension contracture, maximal glenohumeral abduction angle was measured using a goniometer. MicroCT: In order to determine glenohumeral joint congruity, the humerus-scapular unit was obtained with the glenohumeral joint preserved and scanned using microCT. The humerus-supraspinatus unit and scapula were then isolated and scanned again to determine: humeral length, mineralized bone volume of the humeral head, humeral version, area of the glenoid fossa, area of the scapula, glenoid version, and supraspinatus muscle volume. Histology: Each humerus-supraspinatus unit was embedded in paraffin and cut in 5µm sections. The sections were stained with H&E and Toluidine blue. Sections were reviewed for differences in fibrocartilage formation and maturation of the tendon insertion site. Statistical methods: Paired t-tests were made to assess the differences between the operated shoulder and unoperated shoulder within each animal. Differences between the time points were assessed using an ANOVA with planned contrasts. A p-value less than 0.05 was considered significant.

RESULTS: Gross observation: Mice in the Neurotomy group developed an abnormal posture of shoulder internal rotation/adduction and elbow extension in the operated side shortly after the neurotomy procedure. The active motions of the wrist and fingers were well preserved. Mice in the Sham group did not develop any abnormal posture or motion in the operated side. A severe muscle atrophy of the supraspinatus, infraspinatus, and biceps brachii was found in the neurotomized shoulders, whereas no recognizable muscle atrophy was found in the sham-operated shoulders. Joint range of motion: Glenohumeral abduction angle and elbow flexion angle was significantly decreased in the neurotomized shoulders compared to the contralateral normal shoulders, indicating the presence of shoulder adduction contracture and elbow extension contracture, respectively (Fig. 1). Elbow extension contracture became more severe with age. There were no differences when comparing the sham-operated shoulders to their contralateral normal controls. Anatomical parameters: Compared to the normal shoulders, the neurotomized shoulders showed: 1) decreased humeral length and humeral head bone volume at all time points, 2) increased humeral version (i.e. more anteverision) at 8 weeks (Fig. 2), 3) decreased scapular area at 8 weeks (Fig. 3), 4) decreased glenoid area at all time points, 5) decreased supraspinatus muscle volume at all time points (Fig. 4), 6) decreased glenoid version (i.e. more retroversion) at all time points. Humeral head version, scapular area, and supraspinatus muscle volume showed a significant trend for deformity progression with age. There was no apparent subluxation of the humeral head in relation to the glenoid in any of the neurotomized shoulders. There were no differences when comparing the sham-operated shoulders to their contralateral normal controls. Histology: In the neurotomized shoulders, the development of the supraspinatus insertion and articular cartilage was substantially delayed compared to the contralateral normal shoulders (Fig. 5) and the humeral head showed flattening in the superomedial aspect. There was fatty infiltration of the supraspinatus muscle at 4 and 8 weeks. There were no apparent differences when comparing the sham-operated shoulders to their contralateral normal controls.

DISCUSSION: Our animal model successfully utilized surgical denervation of the brachial plexus in neonatal mice to reproduce the bone and joint deformities seen in human neonatal brachial plexus palsy. These included adduction contracture of the shoulder, extension contracture of the elbow, hypoplasia of the humerus and scapula, humeral head flattening, and alteration of the humeral and glenoid version. These deformities became more severe with longer duration of paralysis. Histological examination revealed delayed development of the rotator cuff insertion in the neurotomized shoulders. Our animal model may allow for further research on the mechanism and treatment of shoulder deformities due to neonatal brachial plexus palsy.

REFERENCES