

A New Stabilization Approach to Cadaveric Shoulder Joint Testing

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INTRODUCTION

Shoulder dysfunction is a significant health problem in the US and across most developed countries affecting an estimated 14-50% of the population^{[6][7][1]}. For people who work in the industry or service sectors, the frequency is even higher with at least eight new cases per year for every 100 workers^[2]. The pain and reduced function have a significant impact on people's lives and their ability to maintain employment^[2]. In addition, shoulder pain is common in competitive athletes such as swimmers, and can continue throughout their lifespans^[4].

The common location for shoulder injuries occurs at the socket between the humerus and scapula. This ball and socket mechanism experiences reoccurring stress and often leads to dislocations and rotator cuff injuries. The physiological mechanisms causing most shoulder dysfunction is poorly understood and in many cases, the structural degradation of the tissue surrounding the shoulder is the only focus of rehabilitation specialists as they try to restore function to the shoulder^{[4][5]}. The research objective of the current study was to determine whether abnormal neuronal control and feedback leads to eventual shoulder dysfunction or whether the dysfunction is directly related to the wear on the shoulder capsule connective tissue. Simply, the focus was to determine whether shoulder injuries solely reflect structural failure of the tissue, or if nerve endings misfiring, leading to limited mobility, poor coordination, and higher

pain stimulation, help contribute to these types of shoulder injuries.

A stress-strain curve describes the amount of resistance a material, in this case a shoulder within its socket, imposes on a force. Brittle materials like ceramics have great strength but little elasticity. Polymers have low strength but high elasticity. Stress-strain curves allow one to analyze features such as these in a systematic way. To answer questions posed in this research, the scientists must be able to compare stress-strain curves between multiple human shoulders from people of various sizes and anatomical features in a reproducible manner. The methodology poses a significant problem in itself. An Instron machine is a device that can be used to exert forces on a testing material and quantify the mechanical properties. Using a testing instrument like this on human joints can be quite challenging. To create a valid stress-strain curve, no other sources of applied force can be present throughout the Instron instrument's movement range. With the shoulder containing multiple planes of movement and unique anatomical attributes, that can be a challenging restriction. The focus of this project was to design, manufacture and test an accurate, reproducible, and reliable method for obtaining stress-strain curves of shoulders within their sockets, to allow further research questions to be answered regarding shoulder injuries.

METHODS

In designing this system, it was concluded that a bracket of stiff material would be needed to fix the human cadaveric shoulder. Requirements for the bracket included the need to lock the scapula into a static position, and prevent the distal humerus from moving, although rotation toward the Instron was required. The first iteration of the bracket was a wooden board with screws mounted into the distal humerus. The entirety of the bracket was a wooden 'L' shape with a small crest near the top of the 'L' for scapula fastening and two notches cut out of the sides to allow for proper functionality of the Instron. Screws were drilled through both the scapula and distal humerus to ensure proper fastening. The bracket's overall purpose was to allow a shoulder to be placed into an Instron machine, in which the stress-strain curve of shoulder dislocation would be created. Figure 1 provides the schematic of the wooden device aligned for the scapula, humerus, and distal ulna.

With testing, several limitations of the wooden model were discovered. One of which was that a newly constructed wood bracket was required for each new tested arm, because the screws drilled for one arm would not align with screws drilled for a different sized arm. It was concluded after the wooden brace had been tested that a new bracket design must be created to be reusable. Thus, numerous problems not considered previously, had to be overcome.

First, cadaveric shoulders have bacteria and fluid that can be harmful to a person working in contact with the tissue. This means that the material of the bracket, which will inevitably be layered with these, must be able to be completely sanitized. This rules out the previous wood model. Another problem presented

when considering the frequency the device would be needed; the system had to have high tensile strength and be unyielding. This requirement led toward the preference for metal. Third, because human upper extremities have great variation in bone length and shoulder anatomy, the bracket had to be able to accommodate a variety of shoulders and arm bones, while maintaining a rigorous alignment with the material testing instrument. Thus, it had to be adjustable at several locations and angles. Lastly, the bracket had to be able to fit into the Instron machine without contributing any stresses or strains on the shoulder.

RESULTS

Because of these requirements, aluminum was concluded to be most suitable material for the job. Aluminum is a metal allowing for desirable high stiffness, readily washable with high temperature sanitization techniques, malleable and lightweight, and easy metallurgy. Aluminum is also very inexpensive.

Picking the material for use was not the only problem to overcome in allowing a shoulder to be tested in an Instron device. One of the greatest challenges posed was designing a bracket to accommodate the drastically different lengths of the humerus bone in the test population. Into the new metal 'L' brace, two parallel slots were cut. A slider mechanism rested over the holes and lockable rods allowed the device to accommodate the humerus bone (Figure 2). This new single dimension of freedom was a great improvement from the initial wooden bracket.

In general, the wooden bracket served the purpose by allowing the shoulder to be freely stressed without contacting any of the wood or surrounding material. However, the screw that had previously

been drilled through the distal humerus into the wood to attach the base of the humerus to the wood had significant drawbacks (see Figure 1). Though, this technique of fastening was seemingly functional, it was discovered that this distal screw caused extra stress on the shoulder when forces from the Instron were not parallel to the screw. Essentially, the screw caused a considerable flaw in the produced stress-strain curve because of the moment of inertia it applied. This caused the Instron machine to calculate an elevated level of stiffness. With the screw locked in place, the axes of motion were reduced and the screw itself limited the direction of motion. Thus, the Instron was not only reading the stress that it took to push and pull the shoulder out of the socket, but also the stress that it took to bend the bone into the position resisted by the screw. This created additional dependent variables because long bone mechanical properties, including elasticity, vary greatly from person to person.

To overcome this problem it was noted that, as the Instron pressed up and down on the head of the humerus, the distal humerus normally rotated. For this reason, the new bracket contained a device with an independent block with one degree of rotation and was placed on top of the bracket at the point where the distal humerus connects to the base of the 'L'. The block, setting freely on a rod, then allowed the humerus to rotate freely from external forces of the brace (Figure 2).

Another necessity for the metal bracket was the requirement that the head of the humerus had to be placed in exactly a neutral position of the shoulder within the socket. This would eliminate any extra stress measurements from various muscles stretched when the shoulder was not in a neutral position. Neutrality

depended primarily on the tilt of the humerus toward or away from the scapula. This required another degree of freedom within the brace.

In attempting to solve this problem, fixing the distal humerus directly to the rotating block previously described would be obsolete and would not allow for neutrality to be accomplished. This problem was solved by allowing the block to rotate in a second degree of freedom. By placing a rod through the center of the block, and allowing that rod to shift up and down on either side of the block independently, the block would then rotate in accordance with the rod (Figure 2). The rod could then be adjusted until neutrality within the shoulder occurred and was observed by a fluoroscope. At this point, the rod was locked to ensure complete neutrality throughout the entirety of the Instron motion.

As mentioned, shoulders and scapula vary from person to person, thus the new device had to account for these great variations. Most importantly was the difference in humerus length between people. To allow for this variation, the new rod and block were manufactured to slide back and forth on the short side of the 'L'. The block and rod were placed with a separate square of aluminum, in which two holes were drilled (Figure 2). These holes matched slots drilled into the bracket itself and the square was locked onto the bracket by connecting rods. The functionality of this square allowed the block and rod to slide to the necessary length required by a specific humerus.

Using these ideas, the shoulder bracket had three axes of motion. First, the sliding technique employed at the base of the device in which it could slide toward and away from the scapula. Second, the axle tilt method, in which a tilting rod attached indirectly to the distal humerus allowed

for different degrees of tilt on the humerus itself. Lastly, the ability of the humerus to tilt to and away from the motion of the Instron prevented any external stress occurring in the stress-strain curve. Figures 3 and 4 show a cadaveric humerus bone attached into the bracket device.

Lastly, the scapula had to be locked into place on the top of the 'L' bracket. Because scapulas are very incongruent with respect to size and shape, creating a locking mechanism to account for all geometries of scapulas was a difficult problem. The optimal design was built by placing two bars on the most predictable sides of the scapula (Figure 5). A crest was retained on the bracket behind the wing of the scapula to fasten for stabilization. The crest of the bracket (a block of aluminum screwed through the threaded 'L') fit firmly against the rise between the superior margin and medial angle on the scapula (slightly under the scapula between the two). From there, the two bars were placed and tightened.

Figure 6 demonstrates this locking technique with a human shoulder attached to the bracket at the scapular locking position.

Figure 7 provides a picture of the final product, a bracket that could lock a shoulder into the neutral position prior to testing and maintain that position through the course of the Instron test. Further, the bracket was reusable and sterilizable. It allowed for the necessary degrees of movement while maintaining the shoulder in a precise neutral position. Figure 8 shows a human shoulder mounted onto the bracket in the proper neutral position.

In summary, the aluminum bracket designed for the study allowed optimal fitting to the different shoulders to be tested. Following the manufacturing and testing of the bracket, the shoulder experiments designed to differentiate between neuronal and connective tissue disorders could be completed.

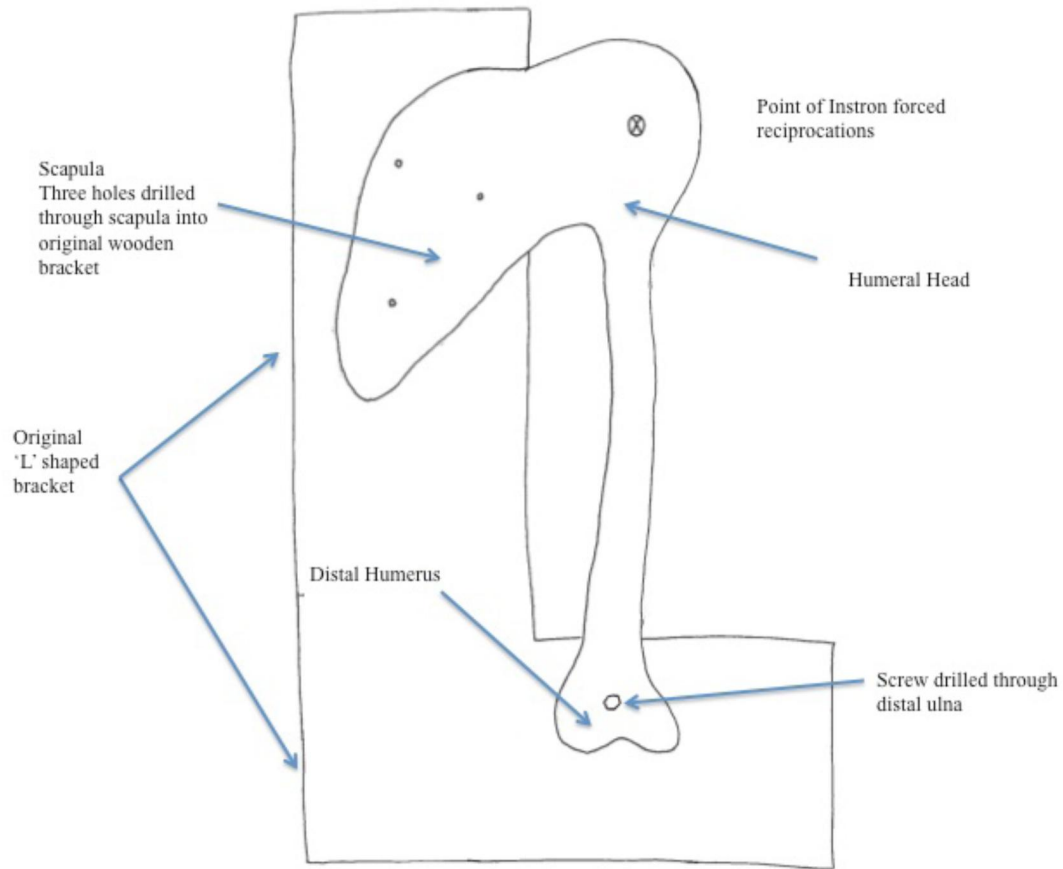


Figure 1:

The original model for the brackets used in shoulder testing included a wooden base with holes drilled through the distal ulna and the central part of the scapula. This method was found to be obsolete because a new base was needed for each shoulder tested.

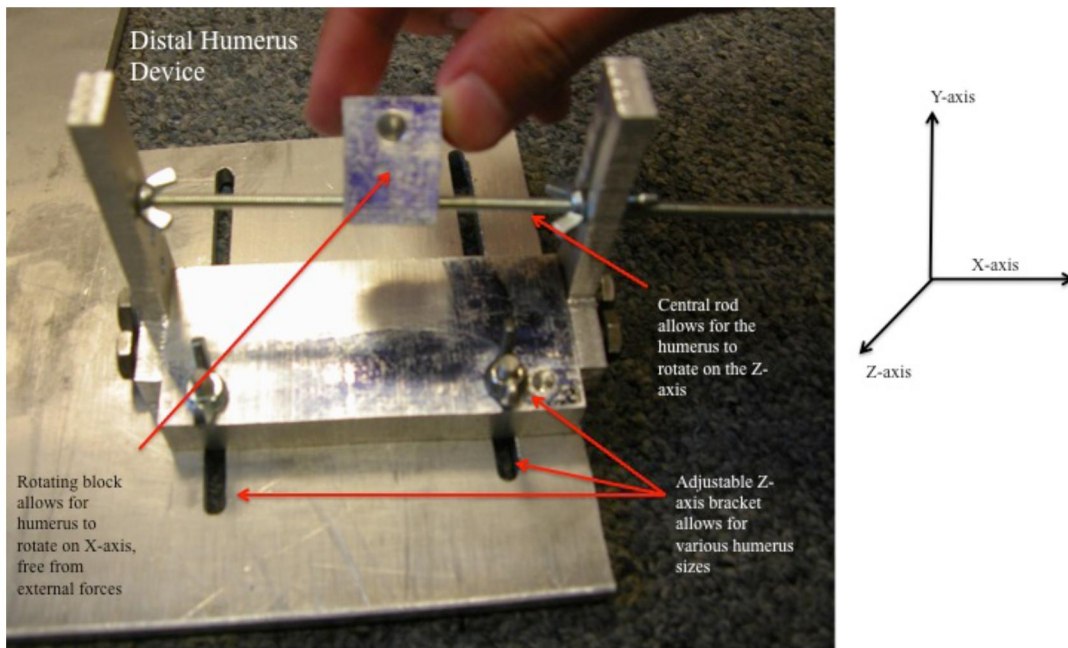


Figure 2:
The device created for mounting the distal humerus incorporates several axis of freedom. The slider mechanism allows for translational movement in the Z-axis. The adjustable rod that acts as the central axis for the block allows for rotation on Z-axis. Lastly, the block itself is able to rotate on the rod, thus allowing free rotation on the X-axis.

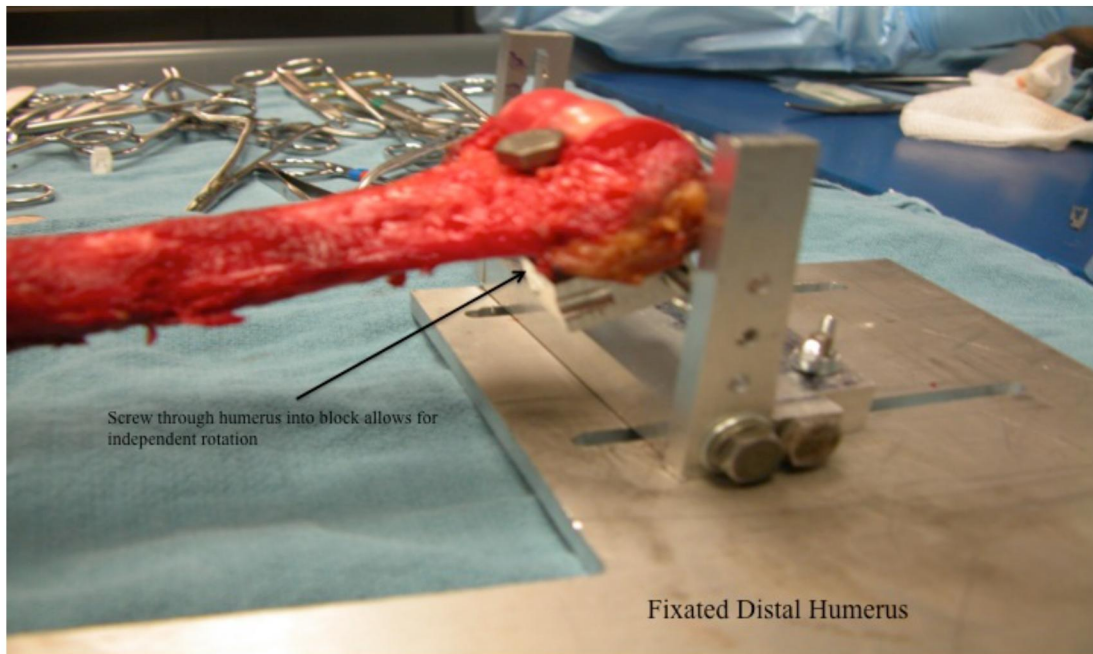


Figure 3:
Drilling through the recession in the distal humerus has no effect on the mechanical strength of the humeral head at the site of force measurements. The screw locks into the threads on the block below. The entire device slides toward the scapular stabilization so that the threads and the screw through the humerus are aligned.

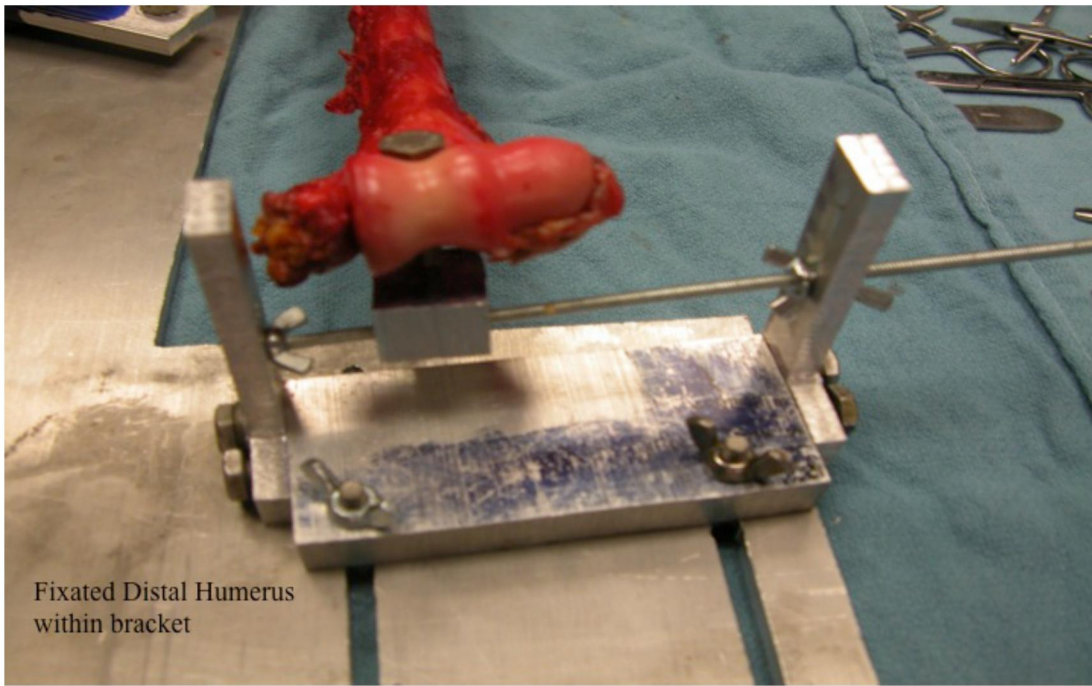


Figure 4
 The distal humerus, now fixated on the bracket, is able to rotate freely as the block rotates on its central axis, the smooth rod. This rod can be moved toward or away from the scapula by simply loosening the wing nuts.

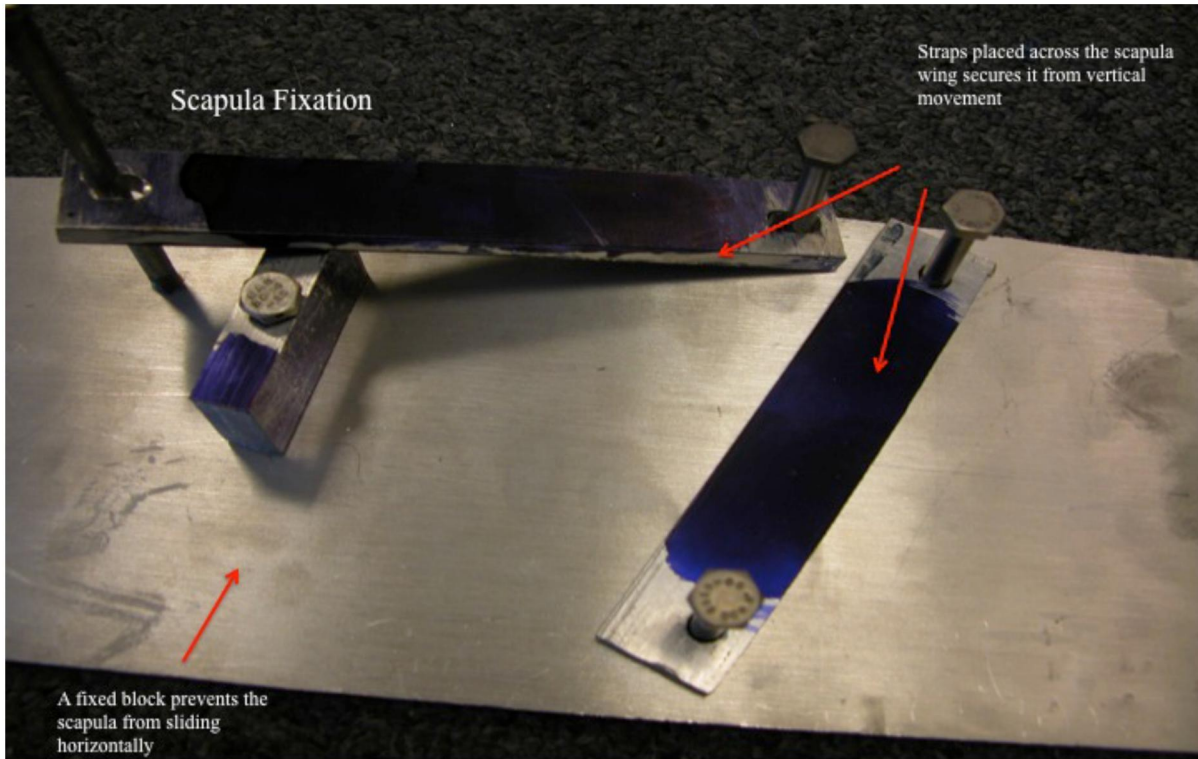


Figure 5:
 The scapula fixation device was required so that no movement from the scapula occurred. Pressing the back of the scapula against the fixed block and strapping the metal bars across the scapula resulted in absolute fixation.

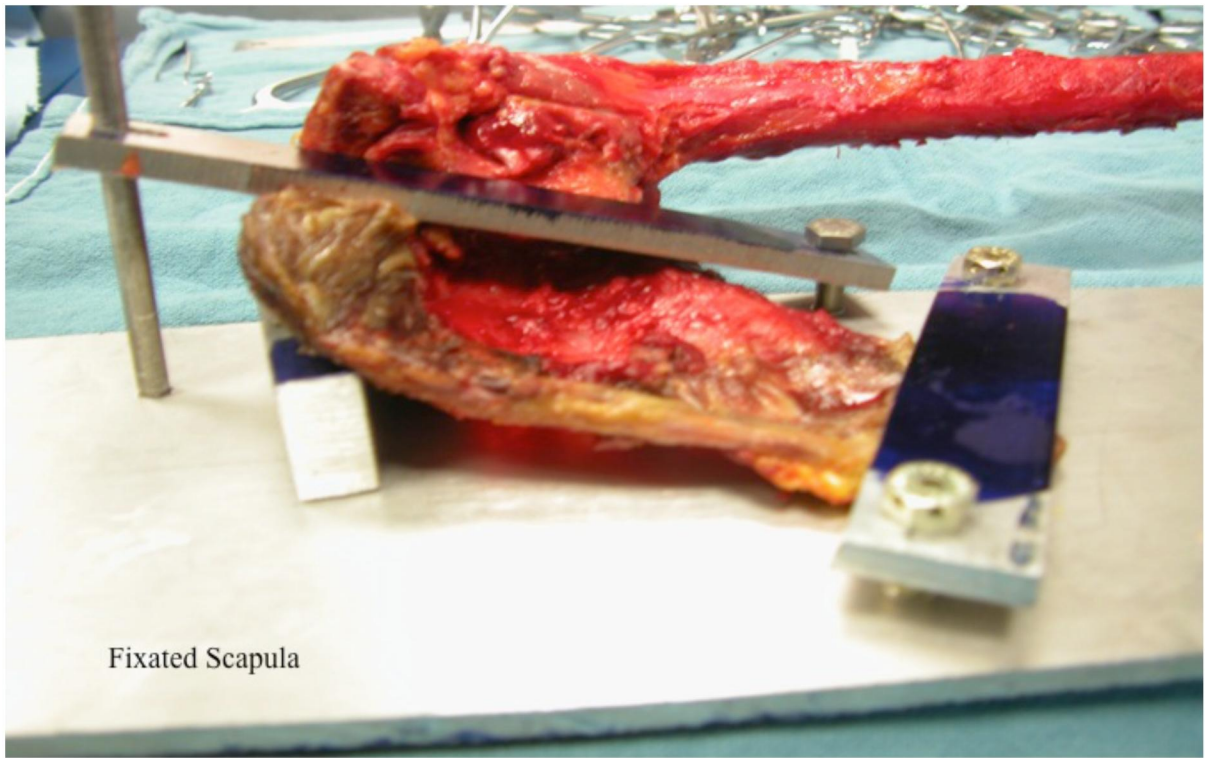


Figure 6:
The scapula, locked by block and straps, was unable to move or contour as forces were applied to the humeral head.

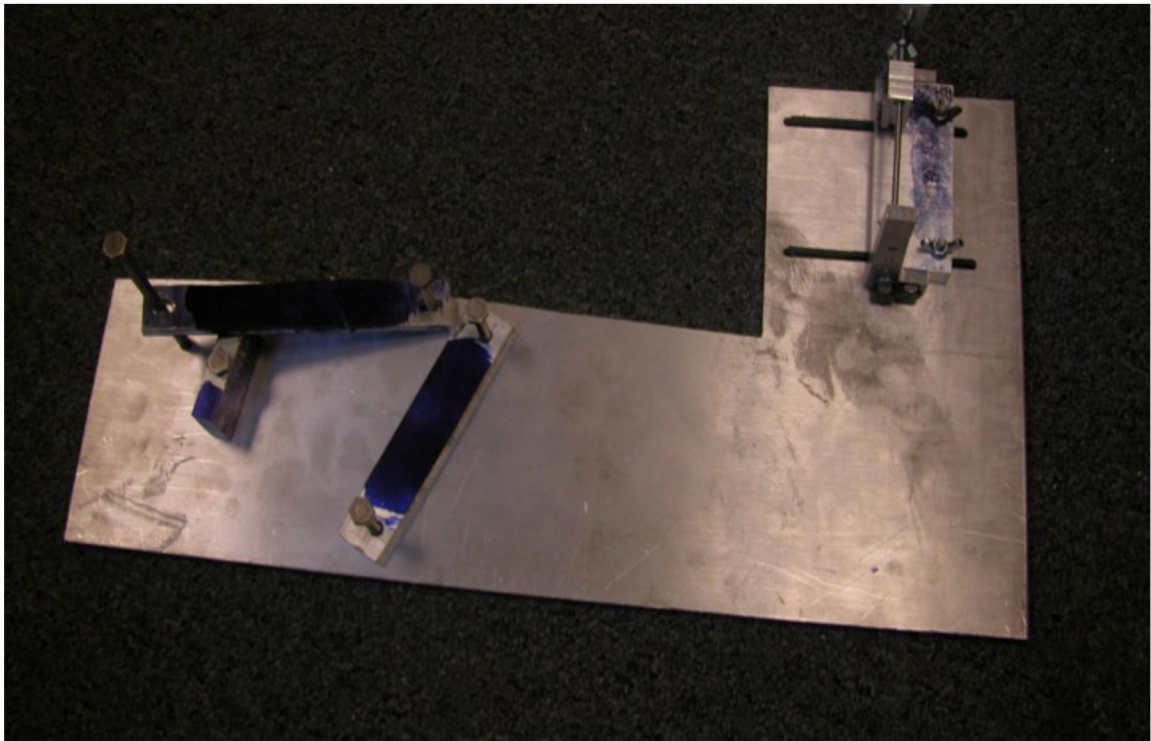


Figure 7:
The final bracket, made from aluminum, has multiple degrees of freedom at the distal humerus and none at the scapula. This model allows for further shoulder testing to be conducted.

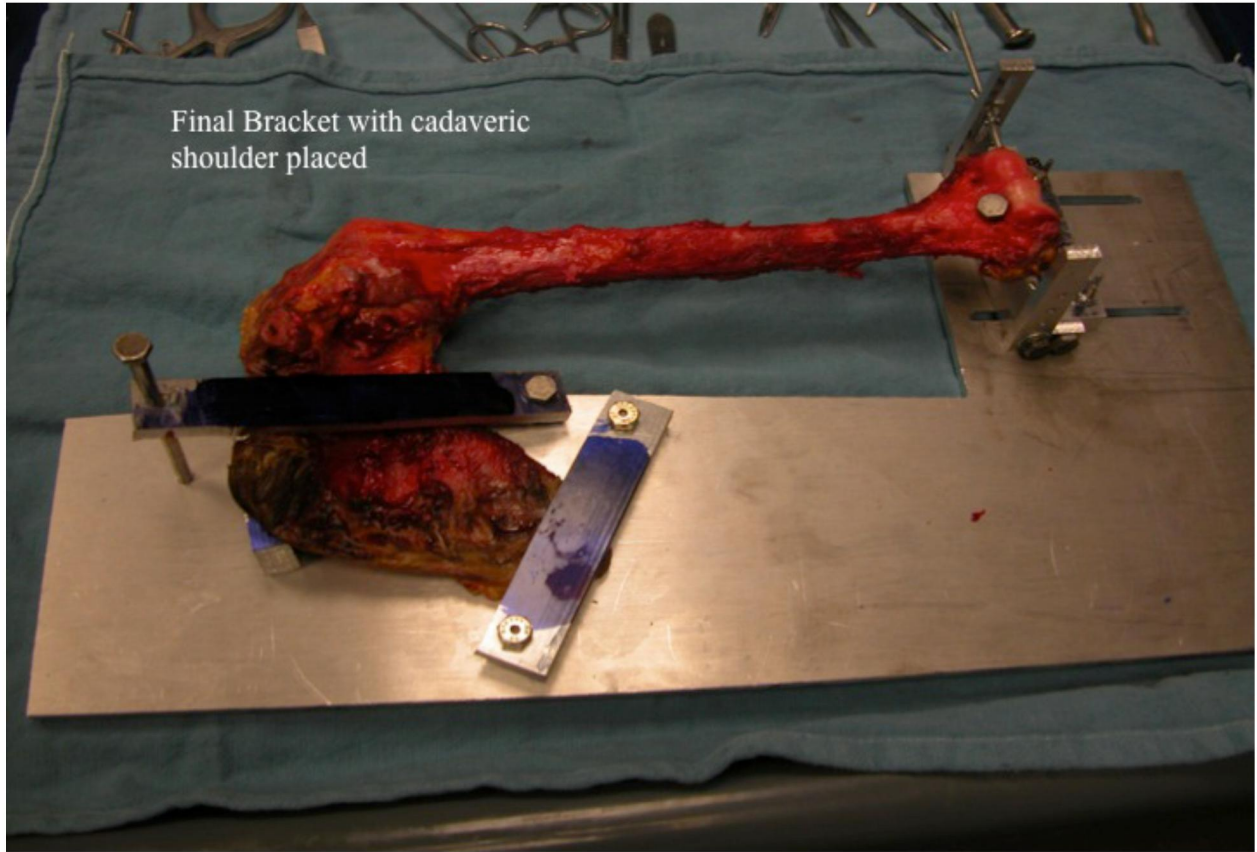


Figure 8:
The completed bracket with shoulder input.

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