Biomechanical Testing of Rabbit Radius/Ulna and Humerus Bones with Various Fixation Techniques to Determine Overall Strength and Stiffness

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Abstract:

The purpose of this study was to determine the optimal fixation technique of rabbit radius/ulna and humerus bones by examining the overall strength and stiffness of intact bones and bones after various repairs. Bones were tested in four-point bending. As the bones were subjected to increased force, both force and displacement measurements were taken. A student's unpaired t-test was used to compare the strength and stiffness of each repair to the intact bones. Our data suggests that the rabbit bones fixed with a locking plate most closely approximates characteristics of intact bones and therefore should be the fixation of choice when repairing these fractures.

Introduction:

Domesticated rabbits have become very popular as household pets in recent years, and their size and tendencies to move about with haste can result in them being accidentally stepped on or jumping out of their owner's arms, which often result in fractures. The repair of rabbit bones is notoriously challenging, as their bones are very small, brittle, and susceptible to further damage during repair. Traditional repairs for radial or humeral fractures involve the use of dynamic compression plates, locking plates, or external fixators. A dynamic compression plate uses screws which are drilled into the bone through a hole in a plate to compress the plate to the surface of the bone and thus provide stability to a surgical repair. A locking plate uses screws which are drilled into the bone through a hole in the plate, but the locking screws, engage threads in each hole of the plate to threads in the screw head, thus attaching to the plate and the bone. An external fixator uses pins which are drilled into the bone and attached to a firm rod or other construct which is on the outside of the skin.

In the rabbit, the radius and ulna are fused and act as one bone, so the radius alone was unable to be tested. In this study, the strength and stiffness of intact bones as well as the various ways of repairing these bones was tested. When looking at how well a fracture repair will work, both the strength and the stiffness are important and should be examined independently from each other. The strength is the amount of force it takes before the bone breaks. The stiffness is the ability of a material to resist changing in conformation, (in this study, the ability to resist bending). The intact bones (radius/ulna and humerus) were tested first to establish the strength and stiffness of each of these bones prior to any repair. Each repair was then tested on the same biomechanical testing device to determine the strength and stiffness of the repaired bone.

Methods/Materials:

Intact radius/ulna and humerus were obtained with the permission of private owners from rabbits which were treated at the Red Bank Veterinary Hospital and were euthanized or died from disease processes not related to orthopedic disease. The bones were measured to ensure that there was minimal variation in size between any of the samples. They were then immediately radiographed after collection and any rabbits with pre-existing orthopedic disease or radiographic abnormalities were eliminated from the study, leaving ten eligible sets to test.

The bones were wrapped in saline soaked gauze and stored in a freezer for preservation until testing. The twenty radius/ulna and twenty humerus bones were randomly assigned into one of four groups (control, plate fixation, locking plate fixation, or external fixator fixator) using a random number generator. All fixations were performed at Red Bank Veterinary Hospital using medical grade orthopedic implants. Plate fixation was performed using stainless steel Synthes 1.5 veterinary cuttable plates and 1.5-millimeter stainless steel screws. Locking plate fixation was performed using OsteoCertus 1.5-millimeter titanium locking plates and 1.5-millimeter titanium screws. External fixators were constructed using 1.5-millimeter stainless steel pins placed in a type two configuration in the radius and a type one configuration with an intramedullary pin in the humerus with Vet-Lite thermoplastic casting material to construct the side bars. After each fixation was applied, the bones were cut with three screws or pins above the cut and three below to simulate a transverse bone fracture. All constructs were radiographed a second time after repair to ensure proper placement of the implants. All constructs were subjected to four-point bending using a homemade tensioning device. (Figure 1 and Figure 2) Displacement was measured using a Rubeder electronic Vernier calipers IP54 with accuracy to 0.01mm, and force was measured with a Sulmile digital force gauge FM-207. Force was applied at a constant rate of approximately one millimeter per minute. Data was recorded and used to generate stress/strain curves for each sample. The strength of each construct was determined to be the maximum amount of newtons that each construct withstood immediately before catastrophic failure. The stiffness of each construct was determined to be the slope of the stress/strain curve within the area of elastic deformation. The difference in strength/stiffness between groups was determined using an unpaired student's t-test with significance set a p-value of less than 0.05.

Figure 1: Biomechanical testing device for testing load and displacement

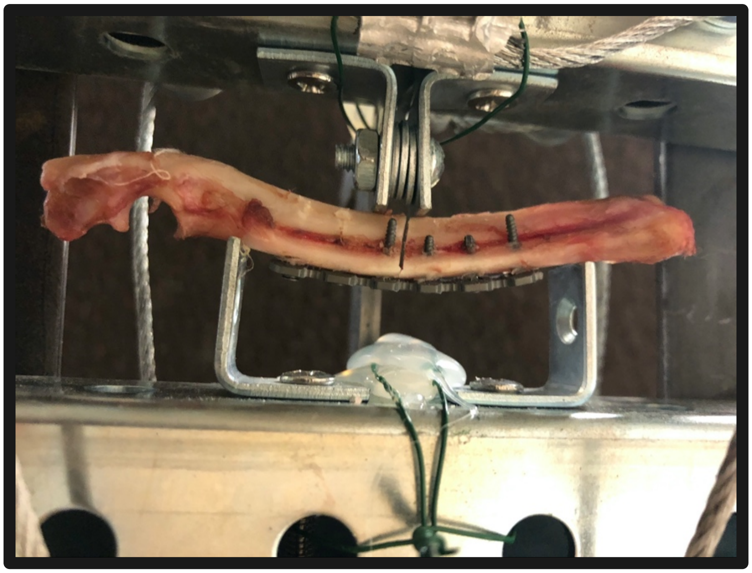

Figure 2—Radius/ulna being tested in 4 point pending

Results:

Radius/Ulna

All statistical analysis was performed using an unpaired student's t-test with statistical significance determined to be $p<0.05$. For each construct, a load vs deformation curve was created. (See Figure 3) The average strength of the control group was 158.44 newtons, the average strength of the locking plate was 68.46 newtons, the average strength of the plate group was 58.96 newtons, and the average strength of the external fixator group was 49.46 newtons. (See Table 1 and Figure 4) There was a statistical difference between the strength of the control and the strength of each repair group. There was no statistically significant difference between the strength of any of the repair groups, although, the strength of the locking plate approached a significant difference from the external fixator ($p=0.09$).

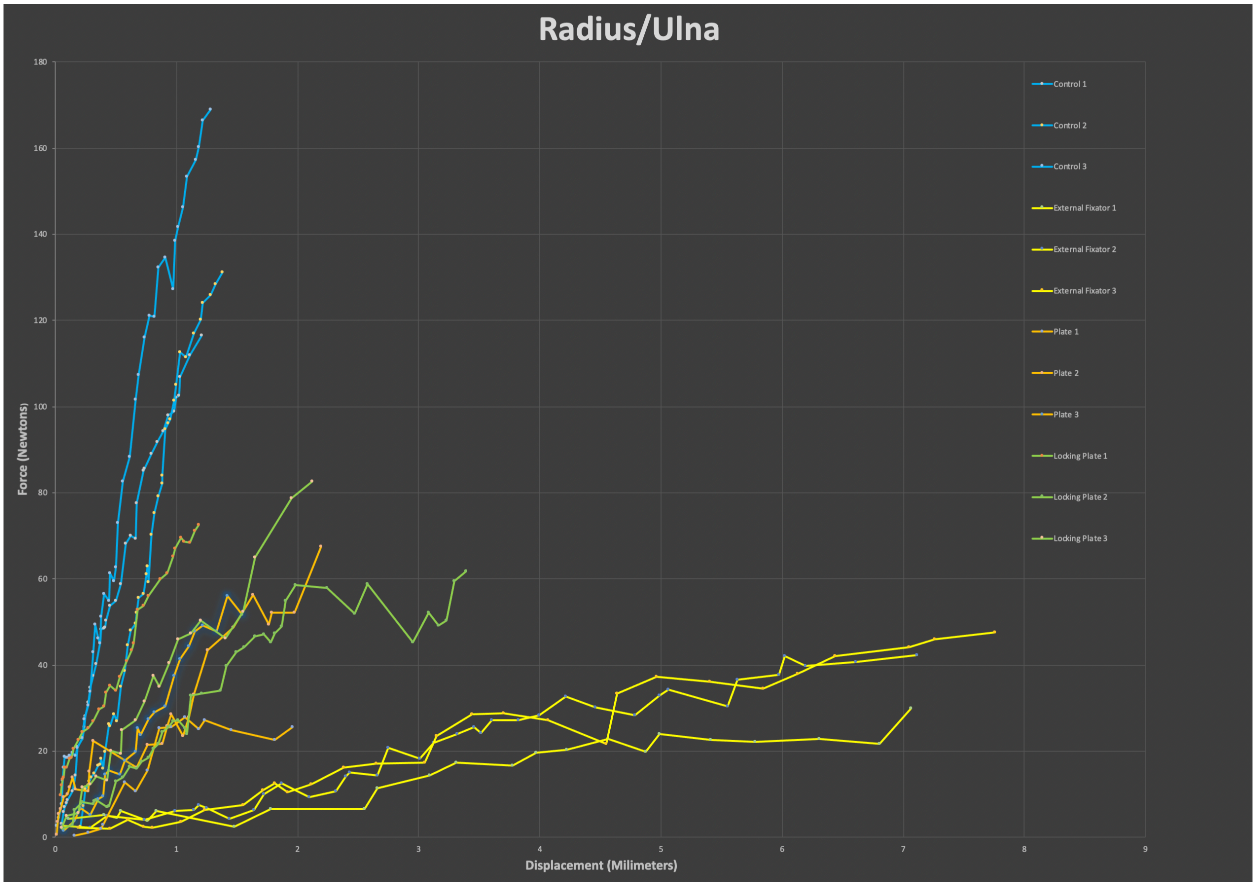

Figure 3: Load/deformation curve of the radius with various repairs. (The three middle curves rather than all 5 were recorded for each construct to simplify the graph)

Table 1: The average strength of each of the 5 trials in newtons (radius/ulna)

Control	158.44 * (significantly stronger than locking plate (p, plate or external fixator)
Locking Plate	68.46
Plate	58.96
External Fixator	49.46

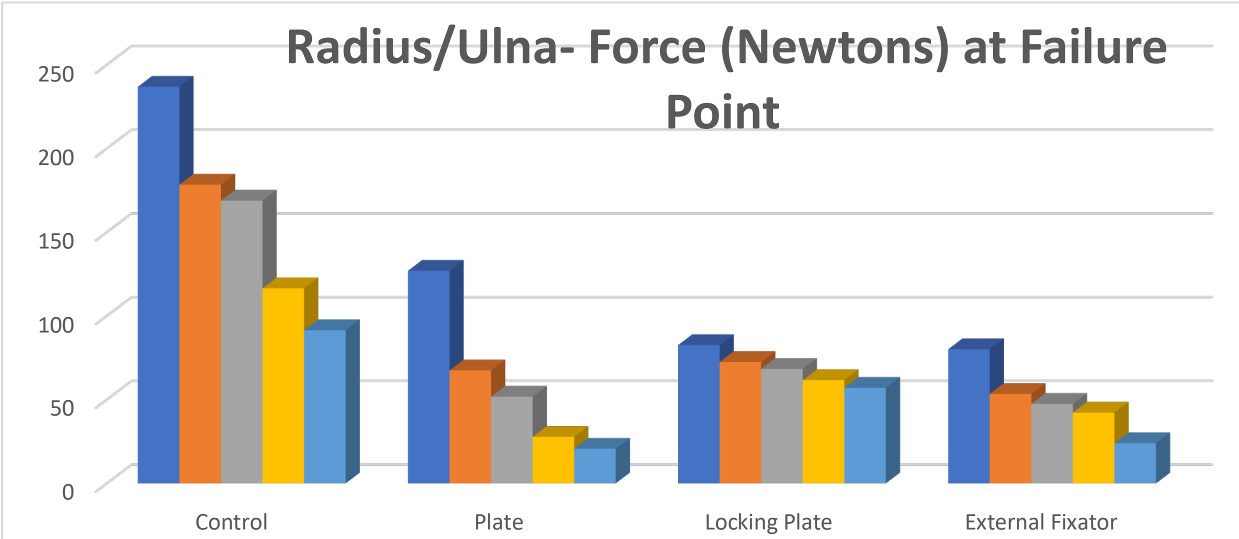

Figure 4: Bar graph of the strength of each radius/ulna construct

The average displacement (millimeters x 10,000/newton) for the control group was 98.29, the average displacement for the locking plate was 215.40, the average displacement for the plate group was 352.13, and the average displacement for the external fixator group was 1309.54. (See table 2 and Figure 5) All fixation groups were less stiff than the control group. The locking plate and plate were stiffer than the external fixator ($p < 0.01$). There was no difference between the stiffness of the plate and the locking plate ($p=0.91$).

Table 2: The average displacement in micrometers/newton of each of the 5 trials in newtons (Radius/ulna)

Control	982.9* (significantly stiffer than locking plate, plate or external fixator)
Locking Plate	2154.0 *(significantly stiffer than external fixator)
Plate	3521.3*(significantly stiffer than external fixator)
External Fixator	13095.4

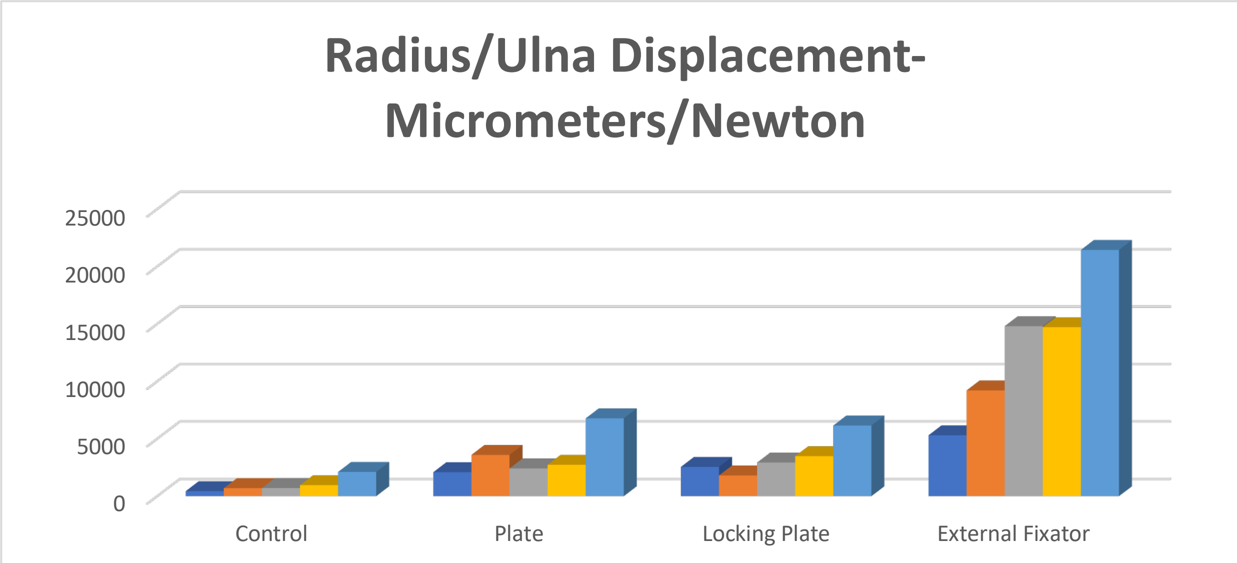

Figure 5: Bar graph of the displacement/unit force of each radius/ulna constructs

Humerus:

For each construct, a load vs deformation curve was created. (See Figure 6) The average strength of the control group was 251.04 newtons, the average strength of the locking plate was 134.44 newtons, the average strength of the plate group was 58.52 newtons, and the average strength of the external fixator group was 76.8 newtons. (see Tablet 3 and Figure 7) There was a statistical difference between the strength of the control and the strength of each repair group. The locking plate was stronger than either the plate (p=0.01) or the external fixator (p=0.02). There was no statistically significant difference between the strength of the plate and the external fixator (p=0.66).

Figure 6: Load/deformation curve of the humerus with various repairs. (The three middle curves rather than all 5 were recorded for each construct to simplify the graph)

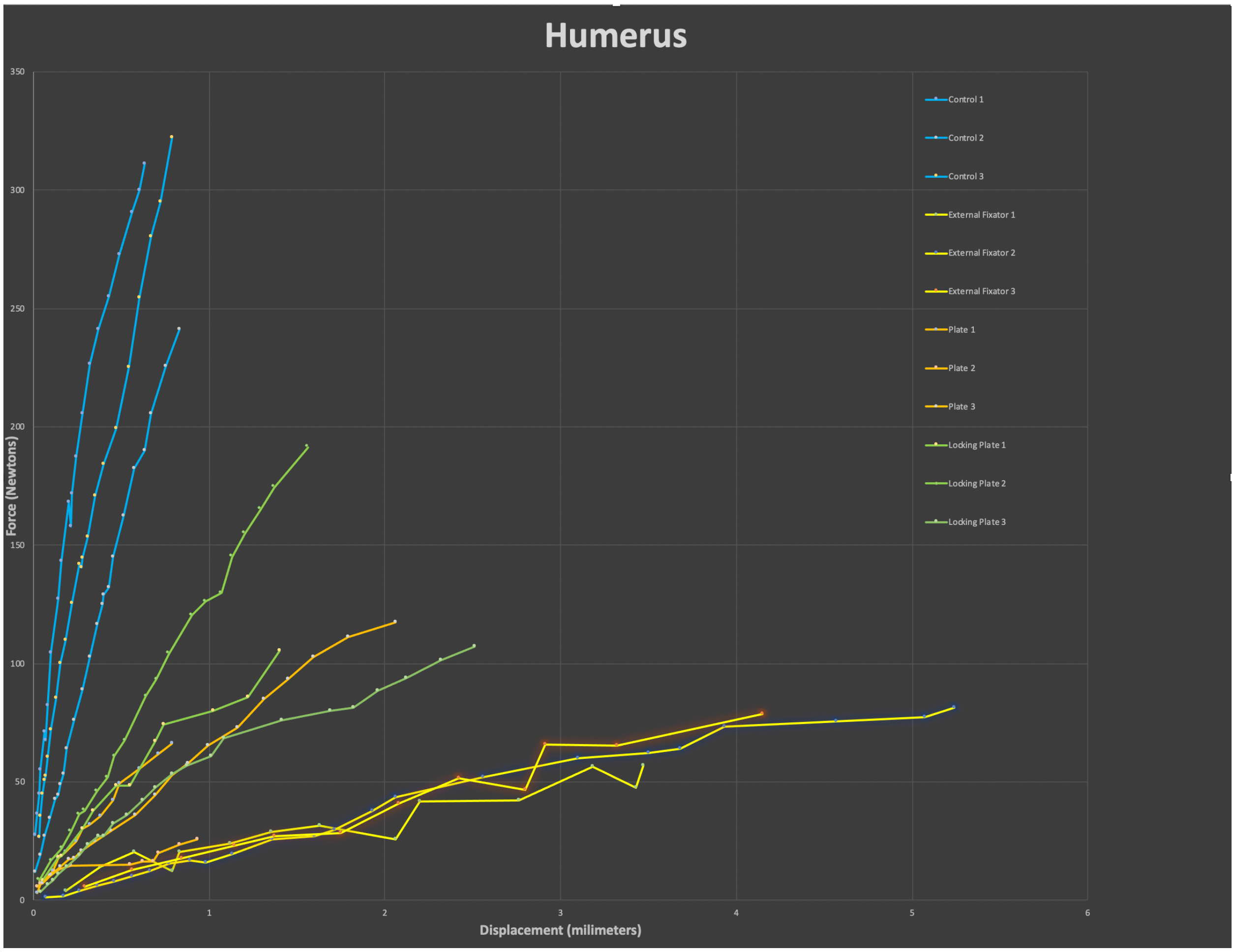

Table 3: The average strength of each of the 5 trials in newtons (humerus)

Control	251.04 * (significantly stronger than locking plate, plate or external fixator)
Locking Plate	134.44 * (significantly stronger than plate or external fixator)
Plate	58.52
External Fixator	76.80

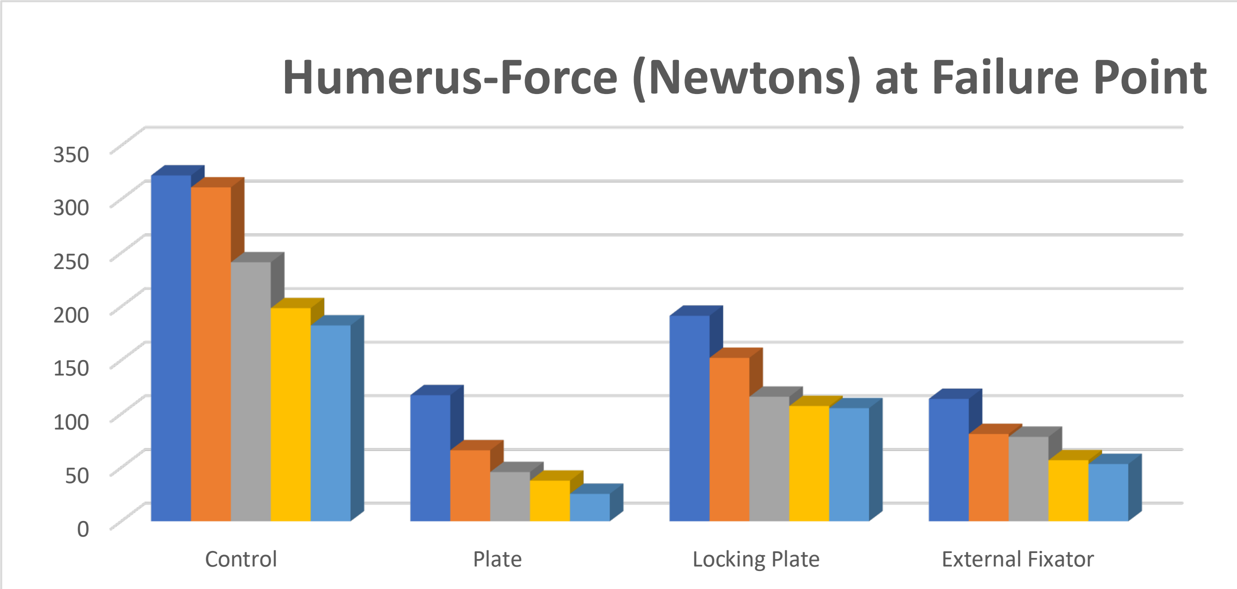

Figure 7: Bar graph of the strength of each humerus construct

The average displacement (millimeters x 10,000/newton) for the control group was 271.76, the average displacement for the locking plate was 181.21, the average displacement for the plate group was 290.43, and the average displacement for the external fixator group was 526.21. (see table 4 and figure 8) There was no difference in the stiffness between the control and the plate (p=0.87), or between the control and the locking plate (p=0.16). The external fixator was less stiff than the control ($p < 0.01$). The locking plate was stiffer than the external fixator (p=0.01). There was no difference between the stiffness of the plate and the locking plate (p=0.35), or the stiffness between the plate and external fixator (p=0.47).

Table 4: The average displacement in micrometers/newton of each of the 5 trials in newtons (Radius/ulna)

Control	2717.6* (significantly stiffer than external fixator)
Locking Plate	1812.1 * (significantly stiffer than external fixator)
Plate	2904.3
External Fixator	5262.1

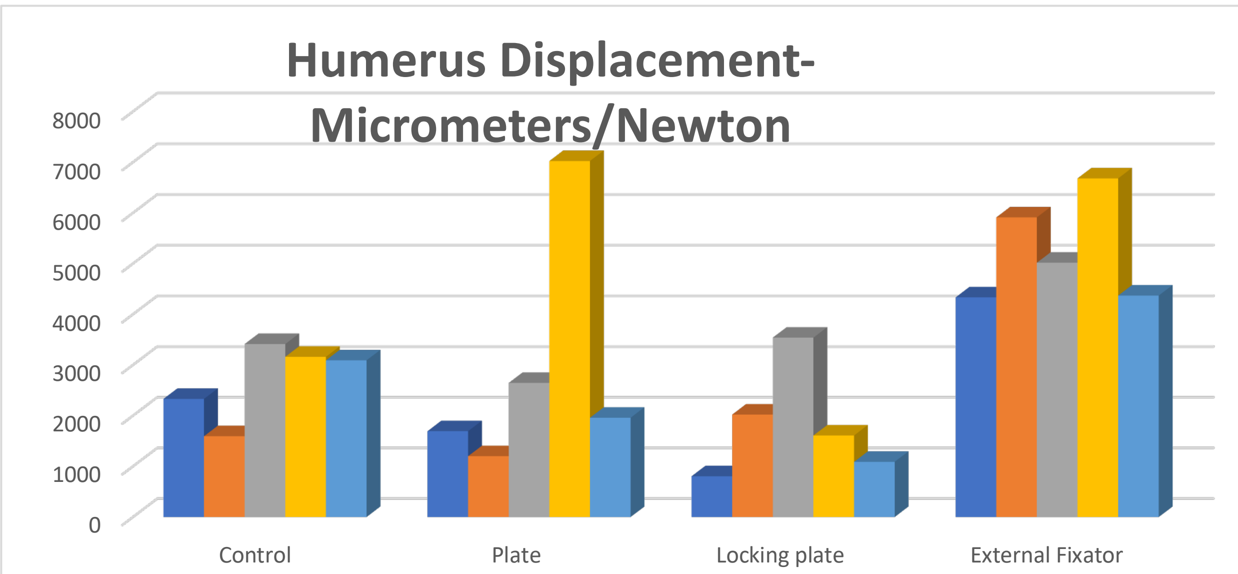

Figure 5: Bar graph of the displacement/unit force of each radius/ulna constructs

Conclusion:

Through this study it was shown that the radius/ulna and humerus were able to be successfully repaired using each of the techniques. Although the strength and stiffness of the intact bones as well as each of the fracture repairs showed some variation between the 5 tests, the results were fairly consistent within the groups. This consistency suggests that the results of this study would be consistent within an array of live patients sustaining fractures and repaired using these techniques. As expected, none of the repairs were as strong as the intact bones. The locking plate was the strongest fixation technique in the humerus and in the radius (results in the radius did not reach statistical significance). The locking plate was the stiffest fixation (least amount of displacement/newton) in the radius/ulna and humerus (statistically significant when compared to external fixator). When tested in 4 point bending, rabbit bones fixed with a locking plate most closely approximate characteristics of intact bones and therefore should be the fixation of choice when repairing these fractures. In the future, this same study can be performed on the femur and tibia of rabbits to determine the optimal fixation techniques for those bones. Also, using these same techniques, the metals used to create the plates and screws can be analyzed separately to determine the optimal substances to perform fixation, and to improve the materials

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