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Research Article

Investigating the Effects of Different Constant Compression Forces on Pig Femur Bone During the Process of Spiral Oblique Long Bone Fracture

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Abstract

Spiral Oblique fractures are a type of bone fracture known to happen by the application of a torsional force while the bone is under certain compression force. The purpose of this re- search is to compare the effects of two different, constant compressional forces during the process of spiral oblique fracture of pig femur bone. Pig bone was chosen for this experiment because potential implications for in Vivo Bone Research made by Aerssens., *et al*. shows that pig and human bones are very closely related on their % of dry bone weight. This experiment will be performed by simulating the fracture with a Materials Testing System (MTS). An epoxy at both, the proximal and distal heads of the bone will stabilize each bone. The bone will then be placed in the MTS. The simulation will be set to apply a constant compressional (Group 1) force on the bone throughout the entire process of spiral oblique fracture. The effects of this compressional force will be tested at 6, 12, and 18 degrees per second. Then a higher compression force (Group 2) will be tested at the same torque speeds, and the measurements of the spiral oblique fracture will be compared and analyzed to define the effects of altering the constant compressional force. Seven bones will be tested for each of the torque speeds on each group (sample size, n = 7). The average angle of twist for the slow, average, and fast rates for Group 1 (500 N, orange bars) were 0.7590, 0.8948, 0.9376 degrees, respectively. The average angle of twist for the slow, average, and fast rates for Group 2 (750 N, blue bars) were 1.3213, 1.2580, 1.7459 degrees, respectively.

The average maximum torque for the slow, average, and fast rates for Group 1 (500 N, orange bars) were 129.4258, 133.6292, 148.4509 degrees, respectively. The average maximum torque for the slow, average, and fast rates for Group 2 (750 N, blue bars) were 123.0230, 113.7802, 135.7897 degrees, respectively. The average angle of fracture for the slow, average, and fast rates for Group 1 (500 N, orange bars) were 64.1919, 59.9131, 66.0148 degrees, respectively. The average angle of fracture for the slow, average, and fast rates for Group 2 (750 N, blue bars) were 72.9282, 69.4060, 71.1549 degrees, respectively. Overall, the fractures made under 750 N were overall cleaner and with higher angles. The proof given by the comparisons between angle of twist, angle of fracture, and maximum torque offer enough evi- dence that a higher compression force creates an overall cleaner and stronger fracture over the spiral oblique fractures of pig femur bone.

Keywords: Spiral Oblique Fracture; Torsional Forces; Pig Femur Bone; MTS; Epoxy; Angle of Fracture; Angle of twist; Maximum Torque

Introduction

A fracture is a break in the bone or cartilage. Long bone fractures are usually a result of sudden trauma from an injury (external forces). These fractures can be caused from overuse in compression/tension and bending moment/torque, also known as stress fractures. Long bone fractures can also be acquired by disease of bone such as osteoporosis or abnormal formation of bone in a congenital disease of bone such as osteogenesis imperfecta. The angle of the fracture is a factor that plays a big role into the type of fracture produced. The angle of a fractured bone can depend on several factors such as the direction of the forces, magnitudes of applied forces, forces' acceleration, forces' frequency, location where forces were applied, area of the pressure on bone, and the moment/torque applied (Dr. Vo, Injury Mechanics Spiral Oblique Fractures Lecture).

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The angle of twist (ϕ) represents the rate of twist per unit length. Figure 1 shows the general forces involved in the creation of an angle of twist. Formula 1 shows the variables needed to obtained the angle of twist. Formula 2 presents the shear modulus for the cortical section of pig bone femur during compression. The cortical Shear Modulus of pic femur is G=1.75 GPa (Mechanical Properties of Biological Materials, Cambridge).

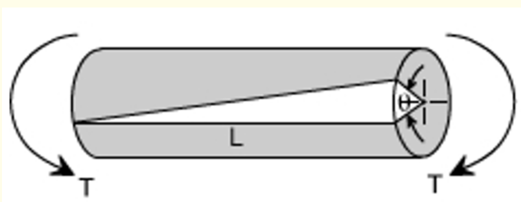

Figure 1: Diagram of forces present for the creation of an angle of twist and angle of fracture.

$Formula\ 1.\ Angle\ of\ Twist: \phi = \frac{!\cdot!}{!\cdot!_!},$

Where, $J_! = \frac{!}{!}(r^!_! - r^!_!)$

T = Torque

L = Diaphysis Length

G = Shear modulus

$Formula\ 2: G = \frac{!|}{!(!!!)},$

Where, Modulus of Elasticity, E = 4.9

Poisson's Ratio, υ = 0.4

Spiral oblique fractures refer to a diagonal break of the bone usually caused by a rotational force applied on the bone. The fracture is said to be oblique when the break has rounded tips, and it is said to be spiral when the break has pointed tips (Dr. Vo, Injury Mechanics Spiral Oblique Fractures Lecture).

The Material testing system (MTS) is an advanced technology that can be used to analyze different materials. MTS can yield results of both static and dynamic material and component testing. The MTS relies on high accuracy, flexibility, and performance. The MTS applies different forces, at different rotational rates in order to create a different variety of breaks altering frequency of torque. This technology allows researchers to recreate different fractures and apply these to bones or other bone like structures. Once an experiment is conducted in the MTS, the technology transfers a complete set of data to the computer software. Allowing the researcher to analyze this data and draw results.

The purpose of this study was to investigate the effects of compression force during the process of a spiral oblique long bone fracture of pig femurs. This experiment was de- signed for placing pig bones on the MTS and simulating a spiral oblique fractures of long bone. This is due to the fact that pig bones, specifically femurs, are one of the animals with the least dissimilar bone characteristics to human bone. In a previous study, it was determined that pig femora should be considered a suitable animal model for the human femur [1].

Prior to beginning the experiment, the team hypothesized that with a higher compression force applied, the resulting spiral oblique fracture would create a better- defined break with a higher angle of fracture.

Materials and Methods

In order to perform this experiment, the first step perform was the skinning of the pig femoral bones. Using a scaffold and pincers, all the meat and tendons was skinned off of each bone. This served the purposes for the bones to maintain a similar range of characteristics so that once bro- ken, the results would reflect the properties of the pure bone. Figure 2 shows the appearance of the bones after this step.

Figure 2: Skinned Pig Femurs.

After the skinning, each of the bones was measured on their overall length, diaphysis length, proximal, diaphysis, and distal circumferences, weight, orientation (left or right), and the shaft diameter.

Once measured, an epoxy was made at both, the proximal and distal head for each of the bones. An Epoxy consists of covering the head of the bone with a mixture of Bondo Fiberglass resin and Bondo hardener. As shown in Figure 3, the bone was fixated and placed in an empty wooden mold covered by a plastic sheet.

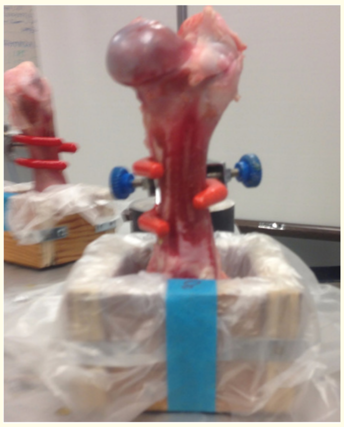

Figure 3: Fixated bone in wooden mold.

The solution was composed of 354.88 ml of the resin and 80 drops of hardener. This solution was then stirred for about 3 minutes and then directly poured it into the mold until the mold was filled. It was essential that the bone was fixated as straight as possible for the epoxy to be done the right way. Then the solution was allowed to sit for 45 to 75 minutes for the fiberglass to become a hard cube encasing the head of the femur.

The epoxy must rest until becoming hard and cold for the femur head to be fixated enough. Otherwise, the epoxy could break during testing resulting on a test failure. Once this process was done, the same process was carried out for the other head of the bone. The final product is shown in Figure 4.

Figure 4: Femur Pig Bones with full epoxy done.

Once the fixtures were set on the MTS, each bone was placed and fitted. At this point the bone was ready for breaking. The MTS test was set for the bone to break under 500N (for Group 1) and 750 N (for Group 2) compression force, with internal rotation motion. The direction of the rotation depended on the orientation of the bone. If it was a left femur, the MTS was set to rotate to the right. If it was a right femur, the MTS was set to rotate to the left. The speed of rotation varied between three different rates: 6 (slow), 12 (average), 18 (fast) Degrees/Second. Once broken the MTS would stop come back to the initial position and store the data in a folder for each specific sample. Figure 5 shows the setup bone on the MTS and a free body diagram of the set up with the forces for spiral oblique fracture for the pig femurs.

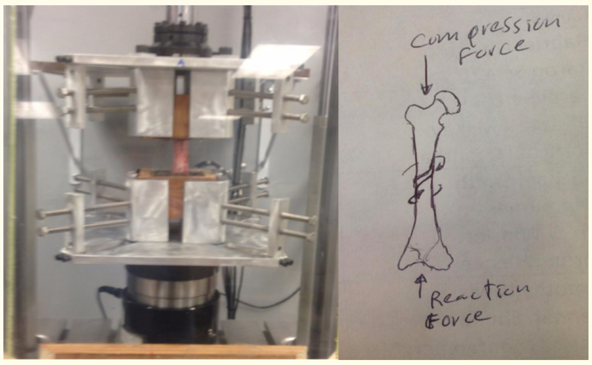

Figure 5: Free body diagram of spiral fracture of pig femur.

Results

The six different groups were compared based on aver- age angle of twist, average max torque, and finally average angle of fracture. The averages of each group were graphed so that they could be more easily compared. A statistical analysis was done on the fracture angle data to tell whether the change in the compression load significantly affected the fracture angle. This was done using IBM SPSS Statis- tics software.

As seen in Figure 6, the compressive load seems to affect the average angle of twist before the fracture. The average angle of twist for the slow, average, and fast rates for Group 1 (500 N, orange bars) were 0.7590, 0.8948, 0.9376 degrees, respectively. The average angle of twist for the slow, average, and fast rates for Group 2 (750 N, blue bars) were 1.3213, 1.2580, 1.7459 degrees, respectively.

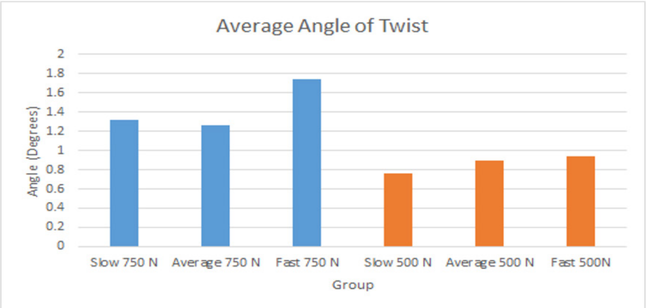

Figure 6: Bar graph reflecting the values for the average Angle of twist for both Group 1 (orange bars) and Group 2 (blue bars).

The average angle of twist for each of the group with a compressive force of 750 N is higher than that of the groups with the 500 N compressive force. The angle of twist seems to increase along with the rotational speed as well as an increase in compression force.

The average maximum torque for each group was graphed, in Figure 7 to analyze the effects of changing the compressional load with regards to the fracturing torque. The average maximum torque for the slow, average, and fast rates for Group 1 (500 N, orange bars) were 129.4258, 133.6292, 148.4509 degrees, respectively. The average maximum torque for the slow, average, and fast rates for Group 2 (750 N, blue bars) were 123.0230, 113.7802, 135.7897 degrees, respectively. The change in the compressional load does appear to have some effect on the maxi- mum torque the femur could withstand. The groups that underwent the 500 N compression force all have higher maximum torques than their corresponding groups with a higher compression force. The increase in compressional force decreased the amount a torque the femur could under- go before fracturing.

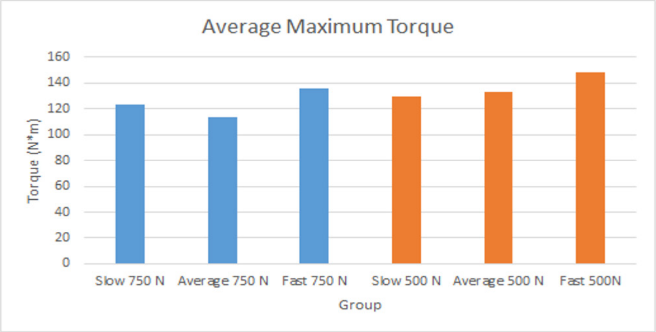

Figure 7: Bar graph reflecting the values for the average Maximum Torque for both Group 1 (orange bars) and Group 2 (blue bars).

The average angle of fracture was graphed, in Figure 8, for each group and a statistical test was done to see if changes in the compressional force significantly affect the fracture angle. The average angle of fracture for the slow, average, and fast rates for Group 1 (500 N, orange bars) were 64.1919, 59.9131, 66.0148 degrees, respectively. The average angle of fracture for the slow, average, and fast rates for Group 2 (750 N, blue bars) were 72.9282, 69.4060, 71.1549 degrees, respectively. Similarly to the angle of twist, there is an increase on the angle of fracture when the compression force is increased from 750N to 500N.

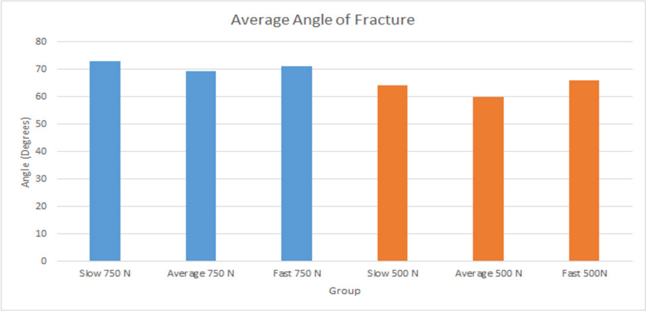

Figure 8: Bar graph reflecting the values for the average Angle of frac- ture for both Group 1 (orange bars) and Group 2 (blue bars).

Three statistical tests were performed on the fracture angle data, Normality test, One Way Anova test, and Scheffe Test for Multiple Comparisons. The data came out to be normally distributed and statistically significantly different with a P-value of 1.56 E-8 [2,3].

Conclusion

The main purpose of this paper was to compare the differences between different compressional forces applied during the process of spiral oblique fracture through pig bone femur. The differences between Group 1 and Group 2 were compared through three different fracture characteristics: average angle of twist, average maximum torque, and average angle of fracture. The values for the angle of twist were all higher when applying 750 N as supposed to 500 N. This offers prove that the application of a higher compressional force increases the rate of twist per unit length. This difference causes the two fragments of the bone, created after the fracture, to split easier during the process of fracture. The higher angle of twist causes the material to reach its torsional failure point faster, taking the material from its elastic region into the plastic region quicker than at lower compression forces. All groups that underwent the 500 N compression force had higher maximum torques than their corresponding groups with a higher compression force. This second comparison agrees with the results found through the angle of twist. The increase in compressional force de- creases the amount a torque the femur could undergo before fracturing. There is an increase on the angle of fracture when the compression force is increased from 500 N to 750N.

This higher angle provides even more prove of the effects of higher compression during the spiral oblique fracture. Overall, the fractures made under 750 N were overall cleaner and with higher angles. The proof given by the comparisons between angle of twist, angle of fracture, and maximum torque offer enough evidence that a higher com- pression force creates an overall cleaner and stronger fracture over the spiral oblique fractures of pig femur bone.

Future studies should definitely consider performing this test on other species such as deer bone and human bone. In addition, another study should be conducted on the testing of other compressional forces, to further back up the effects of compression force proven on this paper. Obtaining data for the same experiment but using maybe compression forces of 250 N and 1000 N would absolutely be beneficial for the overall research.

Acknowledgment

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