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Knee Joint Peri-articular Hardware Sawbones Study

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Abstract

Study of discovering the effect of instrumentation after open reduction internal fixation on knee contact pressures was conducted with sawbones. Four sawbones were utilized, although only two of those, #3172 and #3181, were analyzed for this study because the other two lacked data to compare with the control. For sample #3172, uniaxial loading with average body weight of women and 2.5 times the body weight was done in two conditions: before fixation and with fixation. The process was repeated with sample #3181, which also employed the two types of loading to account for the load variability on knee while walking. In comparison to sample #3172, additional measurements were taken for sample #3181 after removing the plate, to examine if the contact pressure restored its value after the removal. Peak cartilage pressures and the histograms in different conditions were compared to observe the change in pressure with changing conditions. The results of sample #3172 were capricious and ambiguous to conclude whether the fixation had an impact on the contact pressure. Nevertheless, comparison of the pressure of sample #3181 at initial condition with that after the fixation showed a clear increase in contact pressure. With body weight force, the maximum pressure of medial pressure increased from 2.4 MPa to 3.48 MPa. Also, an extra increase in pressure after removal of the plate was noted, which was not as expected. With body weight force, the maximum contact pressure increased from 3.48 MPa to 4.03 MPa. This shows that instrumentation of hardware increases stress on the knee, and retention of hardware does not restore back the pressure. Some sources of error include damage in the sensors, inconsistent location of the sensors, and discrepancy in contact surfaces between the condyles during instrumentation.

Introduction

An injury that is most frequently operated by orthopedic surgeons is tibial plateau fracture, which is a break of the upper part of the tibia that results in movement and ability dysfunctions.[7] Open reduction internal fixation is a common operation done to fix tibial plateau fracture, widely used because of its successful results.[6] Yet the surgery was found to incur secondary osteoarthritis in 44% of the cases in 7.6 years after the fixation.[4] Moreover, the likelihood of total knee arthroplasty increased 5.3 times ten years after the surgery of tibial plateau fracture.[9] The solution to reducing the rate of side effects after the fixation may be found looking into the commonly accepted approach of orthopedic surgeons and discovering the effect of retention of hardware after operative fixation on patients.

One study utilized pediatric cadaver ankles to test total force, peak contact pressure, and contact area before fixation, after fixation, and after removal in order to explore the effect of hardware implant on contact pressures.[8] The study discovered a notable increase in total and peak contact pressures across the ankle joint with hardware in position compared to the samples before fixation.[8] The study then found that screw removal subsequently led to a net decrease in force and peak pressure values while the total contact area remained unchanged.[8] This research refined the method used in examining contact pressures in ankle joint and applied it to examine the knee biomechanics.

Recently, the research of finding the effect of removal of instrumentation on knee contact pressures has been done on cadavers.[1] It showed that after implant removal, there was a higher increase in pressure.

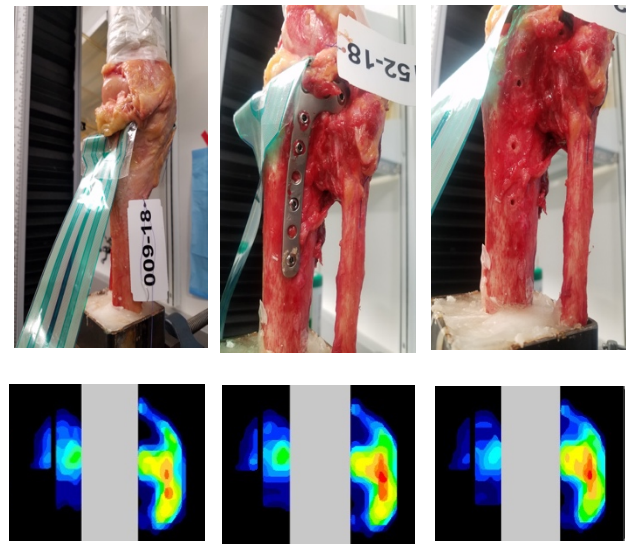

Figure 1: Cadaveric Study (left: Sample in Initial Condition and Corresponding Pressure Map, middle: Sample in Implanted Condition and Corresponding Pressure Map, right: Sample in Removed Condition and Corresponding Pressure Map)[1]

However, cadaveric studies have a lot of variability, especially the screw distance from the tibial plateau in implant placement. This variability was stabilized by using a simulated tibial plateau fixation model. A sawbone model of the human knee was used in place of cadaver tissue. Sawbones are artificial bones that replicate the design as well as the material properties of real bones.[3] A sawbone model was reported to improve the accuracy of biomechanical test set-up due to its uniform size, shape and density.[2] In addition, the use of sawbones allows easier comparison and reproduction of results.[2] This study makes use of these advantages of the sawbones and acquires repeatable measurements that were unviable with the cadaveric study.

Up to now, retention of hardware after operative fixation has been a contentious issue without a definitive answer. If the peri-articular hardware is found to increase contact pressures, hardware removal would be suggested looking further into the health of the knee joint. In addition, if the results demonstrate that the removal of hardware returns the contact pressures across the knee joint back to the original state before instrumentation, taking out the hardware would be further encouraged for decreasing the possibility of secondary future damage. The results could give surgeons a more reliable statistics of whether to remove hardware after fracture healing, and possibly lead to an improvement of clinical practice.

Procedure

Overview: A sawbone model was used to examine whether there are differences in the peak contact pressures across the knee joint before and after simulated tibial plateau fracture fixation utilizing plate implant constructs. Four sawbones model were examined. Two samples, #3814 and #3131, were only tested for contact pressures before the fixation. Another specimen, #3172, was tested in conditions for before fixation and after fixation. The fourth specimen, #3181, was tested in three conditions: before fixation (initial), after fixation with hardware in place (implanted), and after hardware removal (removed). Every specimen was loaded to body weight and 2.5 times body weight. They were performed to simulate forces of standing and ambulation. A body weight of 75 kg was chosen based on the average body weight of female.[5] Although one sensor was planned to be used for one sample throughout testing various conditions, the sensor of sample #3172 was damaged, so one other sensor was used when measuring contact pressure after fixation removal.

<u>Preparing Specimens</u>: Four pairs of sawbone model of a human knee were used for this study. The specimens come in full length of femur and tibia bones. In order to merely focus on the joint contact pressures of those bones and ensure adequate length for potting, specimens were cut through the mid shaft of the femur and tibia using benchtop bandsaw. Fast curing orthodontic acrylic resin powder and liquid were mixed at a ratio of 1 to 1 to prepare for the solution to pot the samples. Both ends that were cut were potted in a frame with knee joint parallel to the ground. The knee joint was adjusted to be parallel to the ground until the polyester resin is dried and solid. To make sure the specimens are potted firmly into the frame and would stay rigid with applied force, they were left untouched for a day. They were labeled with numbers to be differentiated with each other.

Figure 2: Specimen Preparation

<u>Uniaxial Loading Test before Fixation:</u> Once the specimens were prepared, they were set up on an Instron hydraulic testing machine and underwent axial loading. The femur sample was fixed on the hydraulic grip at the upper crosshead whereas the tibia sample was mounted and tightened on top of the lower plate at zero degrees flexion. Considering that the potted tibia samples would

be in slightly different angles and positions in the frame, each sample was adjusted to fit the angle and position of the femur. The femur sample was lowered enough so that it is possible to move the location of the tibia to be aligned with the femur. After the medial and lateral condyle of femur matched those of tibia, tape was used to mark and label the position of each sample. Since one of the significant observations is the footprints of contact pressures, it was crucial to conduct axial loading test for all conditions (before fixation, after fixation, and fixation removal) at a consistent location for each specimen.

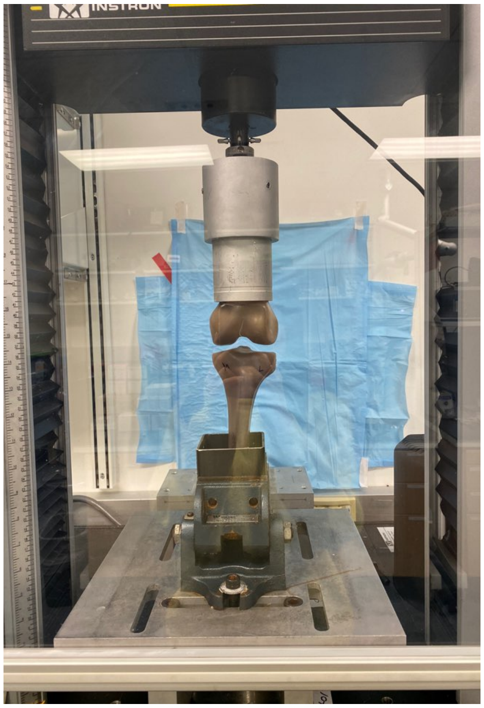

Figure 3: Instron Hydraulic Testing Machine and Specimen

An intra-articular digital pressure sensor was placed on the tibial plateau, intercalated in between two rubbers. Rubbers help distribute the pressure and represent the interarticular cartilage since they have similar material properties. Tekscan 4015 intra-articular digital pressure sensors were calibrated according to manufacturer's specification. In this study, 10 trials across the range of 300 N to 1200 N were used to calibrate the sensors. In order to calibrate, the machine was manually adjusted to unload completely, and the upper crosshead was lowered until the loaded amount reached the desired load. I-Scan was utilized to type in the load applied and calibrate the sensor at that condition. After repeating this step for 10 different loading points, axial loading was performed twice with load equal to body weight in order to account for variability. After saving the data, the test was performed twice with load equal to 2.5 times the body weight. This process was repeated all four tibia samples after calibrating each sensor for each sample. These results before fixation were served as control.

Uniaxial Loading Test with Fixation: In order to measure the contact pressures across the knee joint with hardware in place, the tibia samples, #3172 and #3181 were instrumented. After implanting the plate onto the sample, it was mounted back to the lower plate of the hydraulic testing machine. The sample was located back to where it was marked when measuring the contact pressures before fixation. Using the sensor calibrated before for the same sample, the process of measuring contact pressures was again performed through uniaxial loading test with body weight and 2.5 x body weight.

Uniaxial Loading Test after Fixation Removal: The screws on #3181 were all taken out in preparation for implant removal condition. At the exact location where the contact pressures for before implant and with implant were measured, the sample was again tested with body weight and 2.5 x body weight, in order to simulate various points during the gait cycle.

Comparison of the Contact Pressures: The sensor had medial and lateral condyles to it. The two sides were observed separately throughout the analyses. When measuring the contact pressures, we used I-Scan to record the movie of the testing process in 100 frames. For every movie, 100 frames were averaged out to get one pressure map. The two average pressure maps of two trials for each testing condition were then be averaged for one final pressure map.

Results

Due to the specific aims of this research, only the data for two samples, #3181 and #3172, were analyzed since #3181 had measurements to compare the initial values with values with plate on and after plate removal, and #3172 had measurements to compare the initial values with values with plate on. Microsoft excel was utilized to develop histograms for the number of contact pressure values within a range. This allowed for a more obvious analysis and comparison of distribution of contact pressures.

First, the sample of #3181 was examined with the body weight force acting upon it. The maximum pressure of the sample with plate on turned out to be 3.48 MPa when that of the sample before instrumentation was 2.40 MPa. The relative histogram is included below.

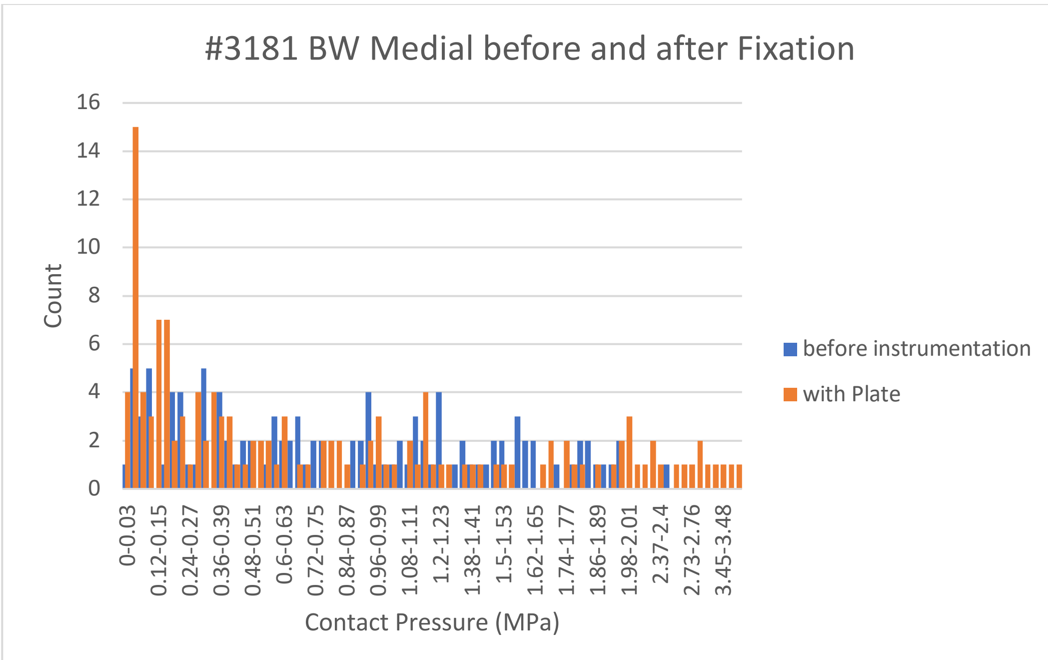

Figure 4: #3181 Body Weight Medial Contact Pressure before Plate on and with Plate on

Again, the maximum cartilage contact pressures were compared for samples with hardware implant and after removing the hardware. The maximum contact pressure for the sawbone with plate after plate removal was 4.03 MPa. Histograms were made to see if the pressures reinstated to original values.

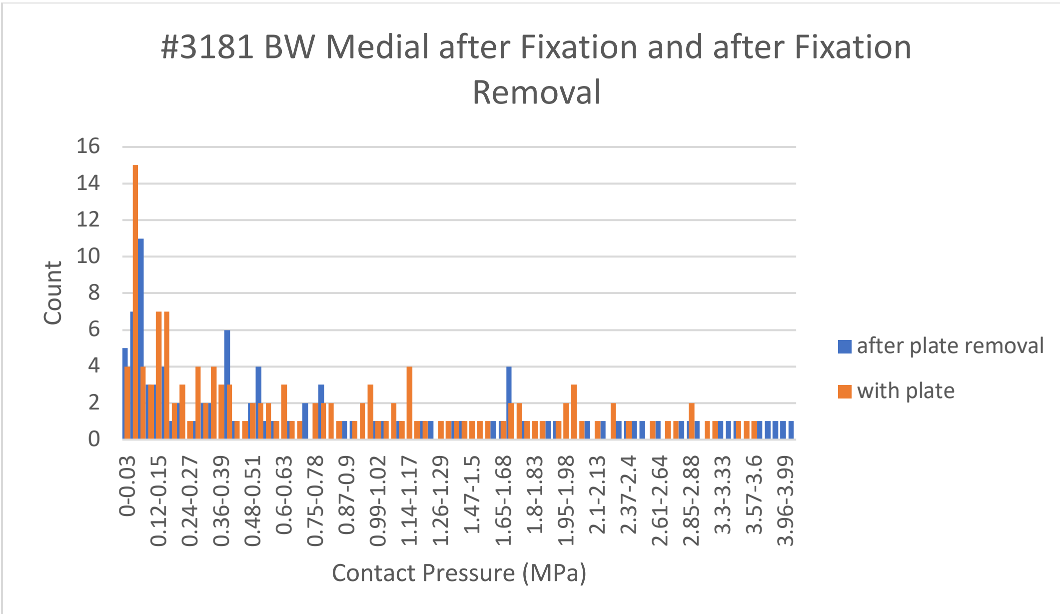

Figure 5: #3181 Body Weight Medial Contact Pressure with Plate on and after Plate Removal

Same analyses were done for the lateral condyle of the sample. Maximum pressure before plate instrumentation was 2.88 MPa whereas that with plate instrumentation was 4.50 MPa. Histogram is shown below in Figure 6.

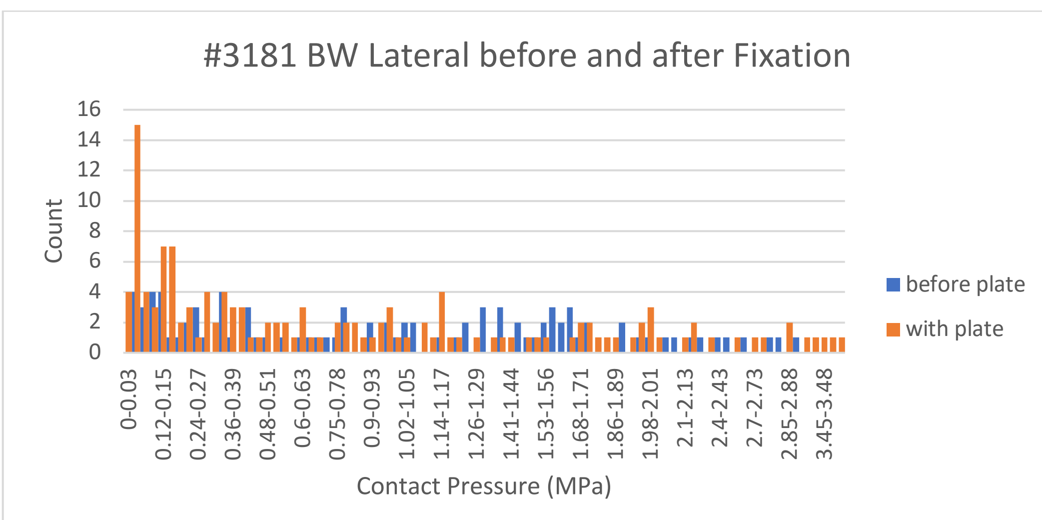

Figure 6: #3181 Body Weight Lateral Contact Pressure before Plate on and with Plate on

The maximum contact pressures for body weight force on lateral condyle for plate on and after plate removal were 4.50 MPa and 5.31 MPa, respectively.

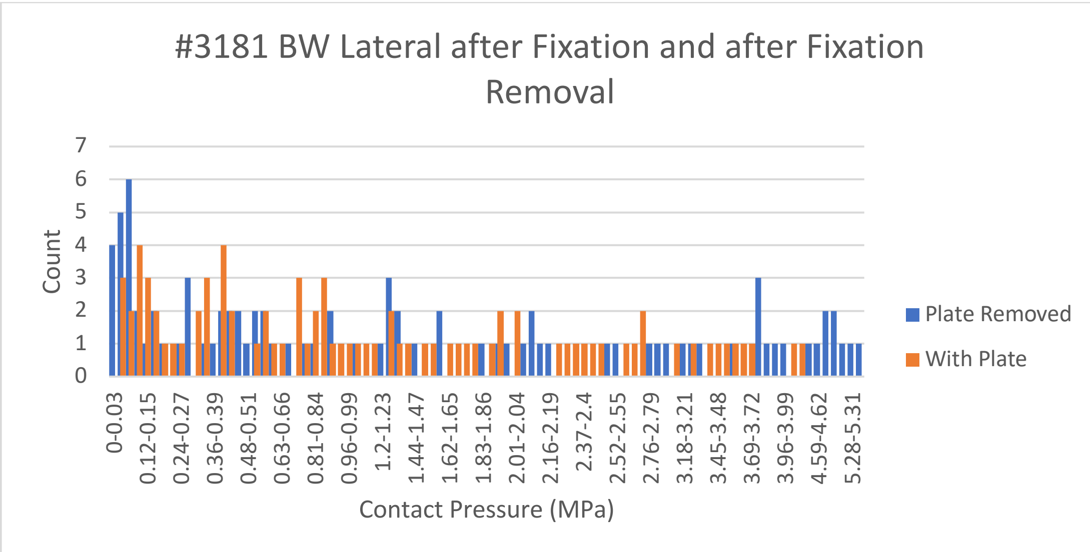

Figure 7: #3181 Body Weight Lateral Contact Pressure with Plate on and after Plate Removal

Then, the contact pressures for 2.5 x body weight force were observed and measured. The maximum pressure for the medial condyle for plate #3181 before plate instrumentation, after plate instrumentation, and after plate removal were 2.52 MPa, 3.89 MPa, and 5.01 MPa, respectively. The two graphs below demonstrate histograms of 2.5 x body weight applied contact pressure difference for medial condyle comparing the three conditions, before plate on, with plate on, and after plate removal.

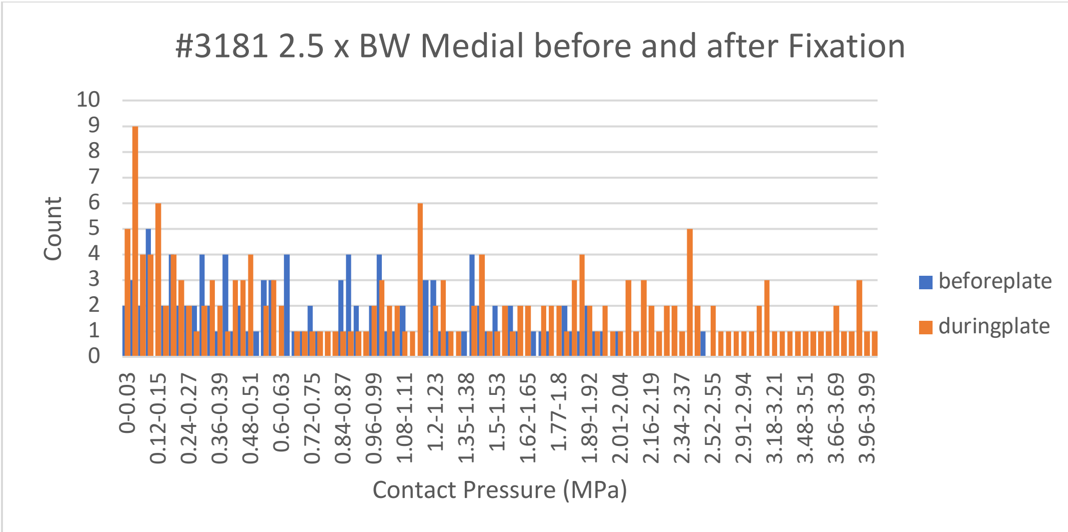

Figure 8: #3181 2.5 x Body Weight Medial Contact Pressure before Plate on and with Plate on

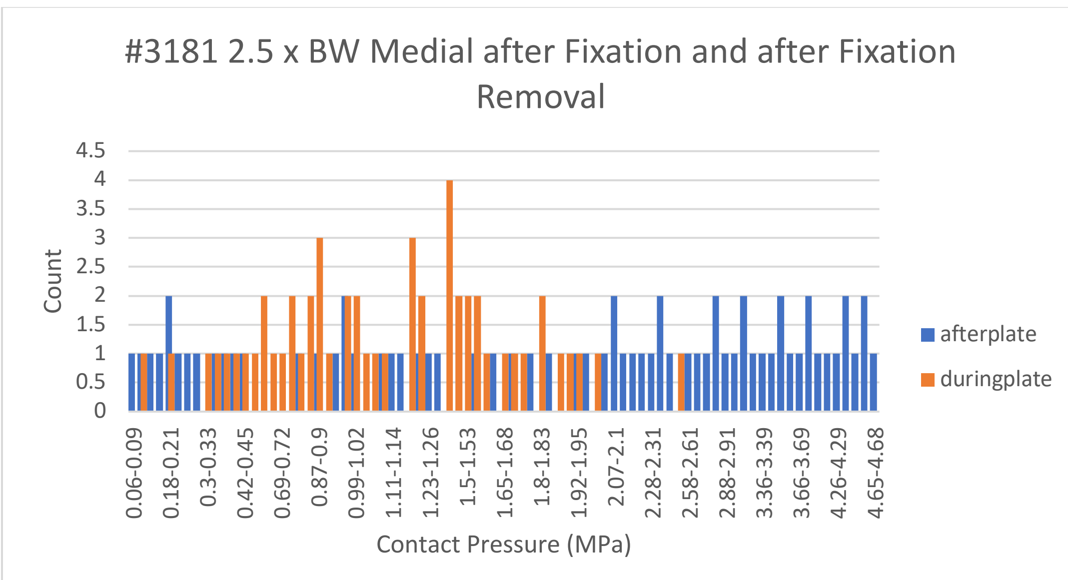

Figure 9: #3181 2.5 x Body Weight Medial Contact Pressure with Plate on and after Plate Removal

The two graphs below show histograms of 2.5 x body weight applied contact pressure difference for the lateral condyle comparing the three conditions, before plate on, with plate on, and after plate removal. Peak contact pressure changed from 2.79 MPa to 4.61 MPa, and 4.61 MPa to 4.54 MPa.

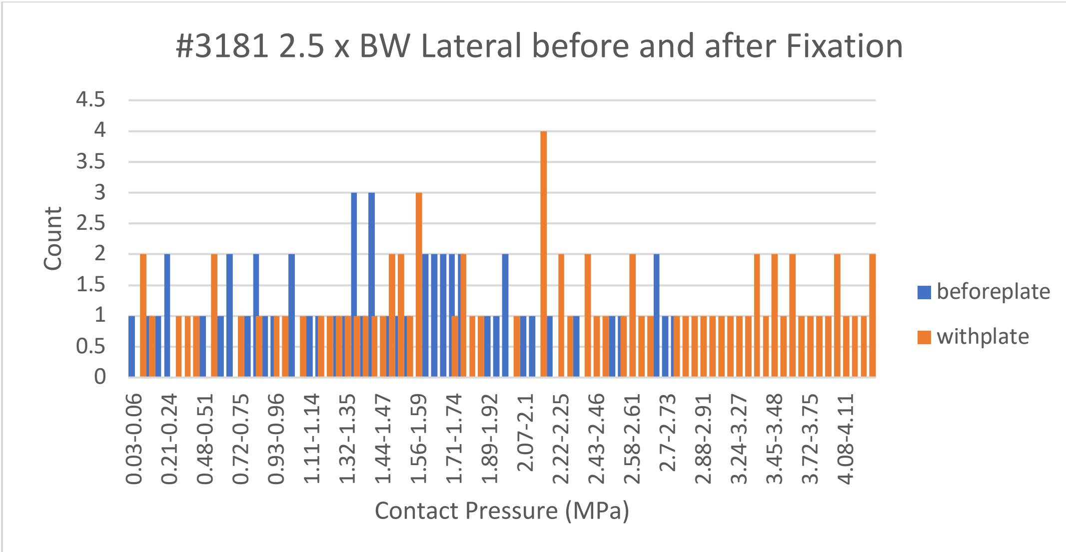

Figure 10: #3181 2.5 x Body Weight Lateral Contact Pressure before Plate on and with Plate on

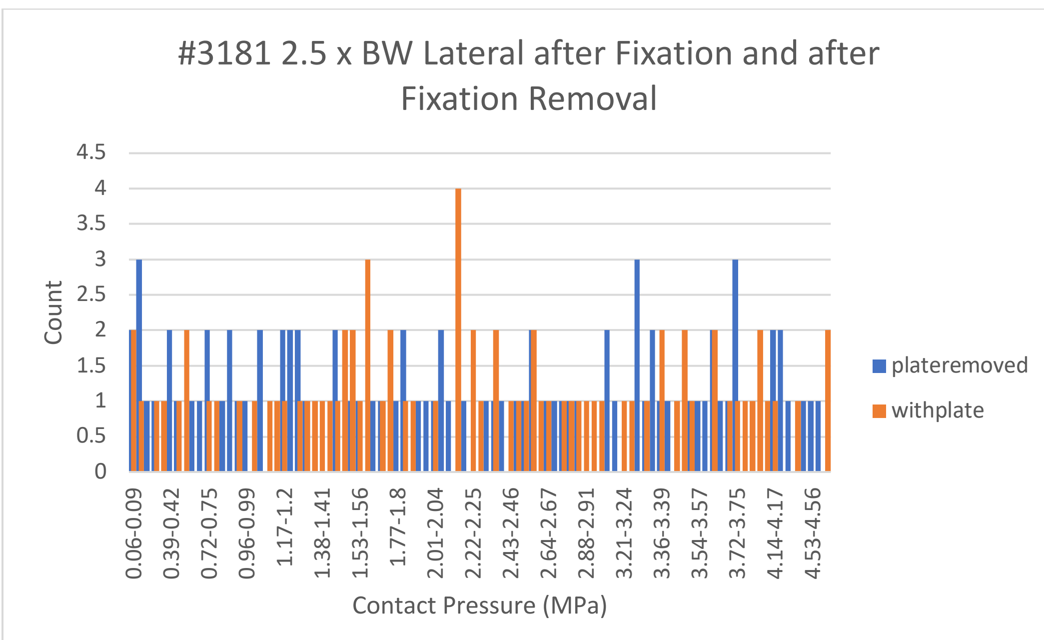

Figure 11: #3181 2.5 x Body Weight Lateral Contact Pressure with Plate on and after Plate Removal

Next, data for the sample #3172 were organized in histograms to examine pressure distributions for medial and lateral condyle before and with the instrumentation. Peak cartilage pressure for medial condyles loaded with body weight before fixation was 4.21 MPa whereas that after fixation was 4.65 MPa. Histograms for sample #3172 for both conditions fluctuate throughout the whole range.

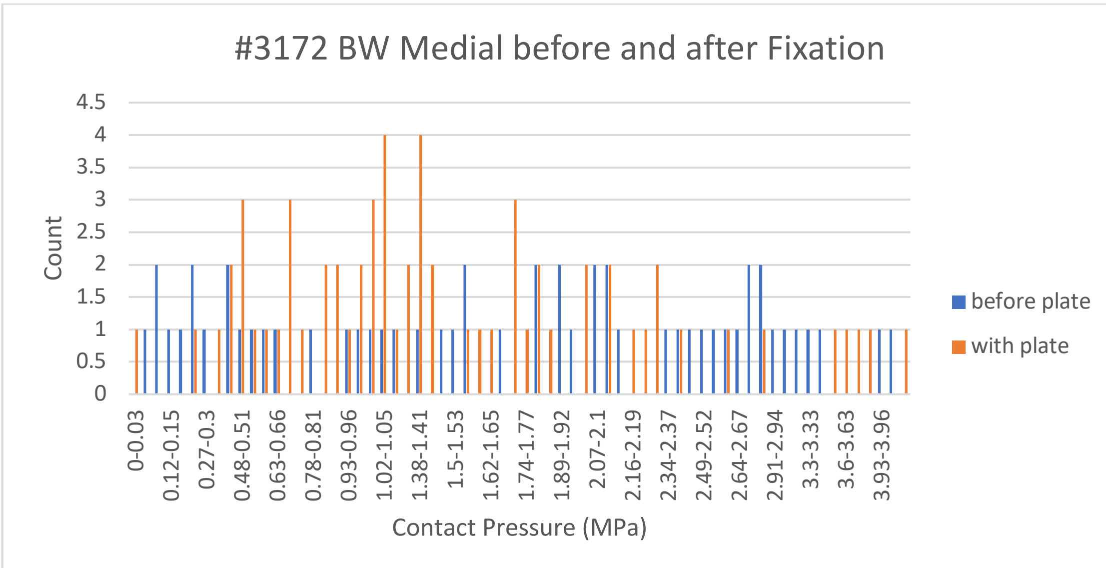

Figure 12: #3172 Body Weight Medial Contact Pressure before Plate on and with Plate on

Peak cartilage pressure for lateral condyle loaded with body weight before fixation was 4.43 MPa whereas that after fixation was 3.12 MPa. Contact pressures decreased with instrumentation.

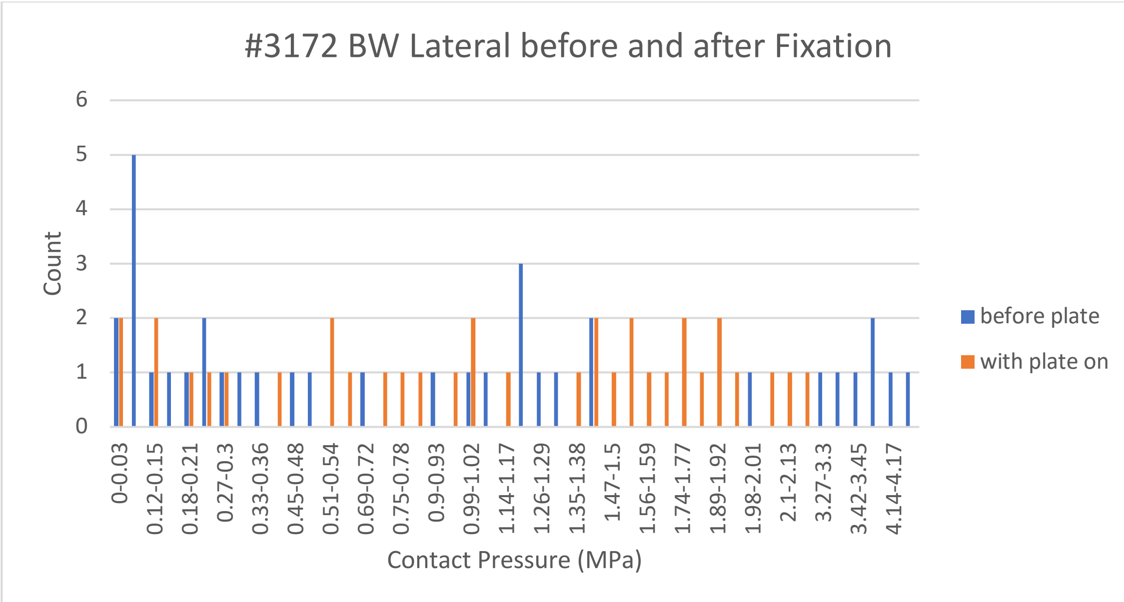

Figure 13: #3172 Body Weight Lateral Contact Pressure before Plate on and with Plate on

Peak cartilage pressure for medial condyle loaded with 2.5 x body weight force before fixation was 6.40 MPa whereas that after fixation was 7.68 MPa.

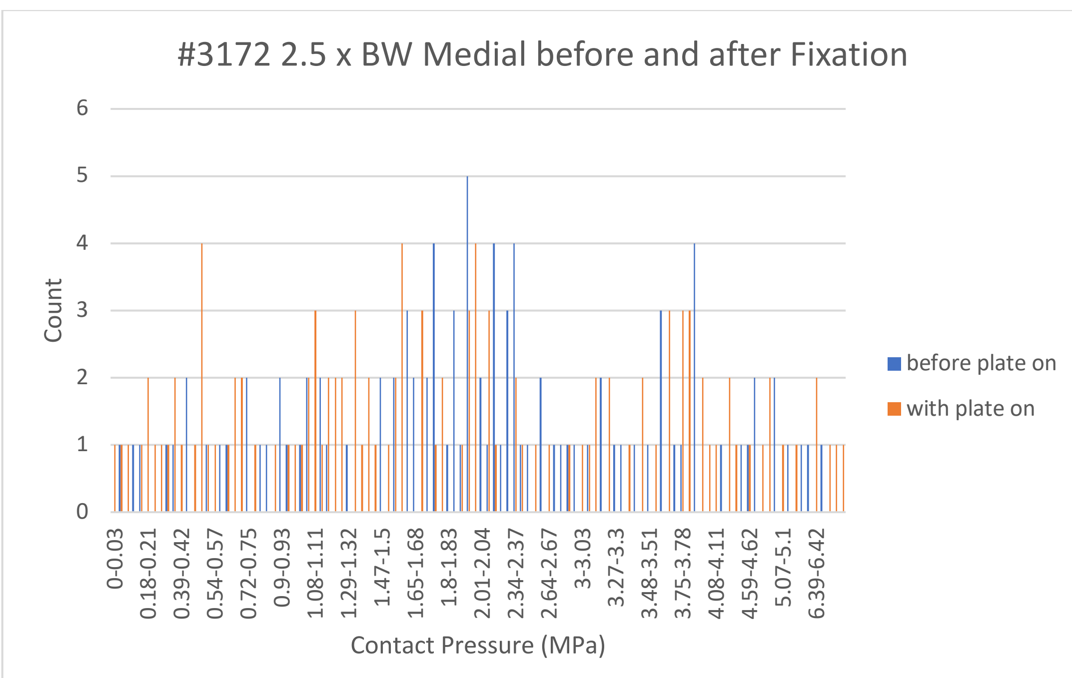

Figure 14: #3172 2.5 x Body Weight Medial Contact Pressure before Plate on and with Plate on

Maximum contact pressure for lateral condyle loaded with 2.5 x body weight force before fixation was 11.03 MPa whereas that after fixation was 6.77 MPa. Overall contact pressure decreased after fixation.

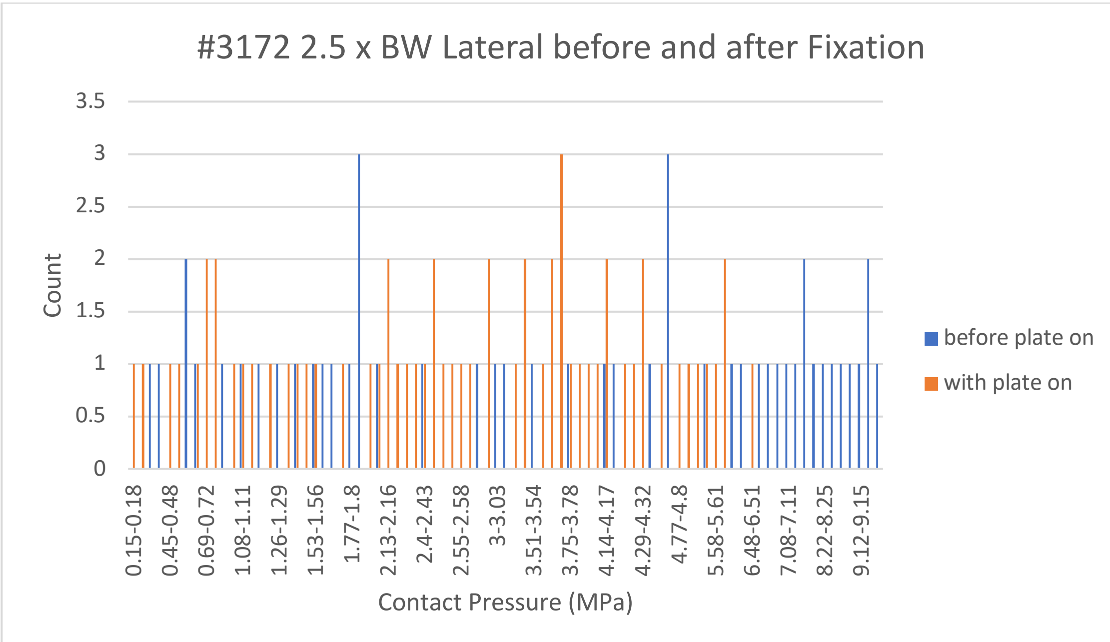

Figure 15: #3172 2.5 x Body Weight Lateral Contact Pressure before Plate on and with Plate on

Discussions

Figures 12, 13, 14, and 15 show results of sample #3172 comparing contact pressures at initial condition with those after fixation. However, distribution of contact pressures of sawbone #3172 was difficult to tell if the contact pressure decreased or increased after instrumentation. The histograms demonstrated higher contact pressures for plate on in the middle range but showed higher maximum pressure for samples before instrumentation. Overall, they fluctuated without a clear guide. For body weight medial and 2.5 x body weight medial, the peak contact pressure was higher for the sample with instrumentation whereas for body weight lateral and 2.5 x body weight lateral, the peak contact pressure was higher for the sample before instrumentation. The results did not demonstrate any pattern, which was not as expected. This might be due to the inconsistent contact surfaces between the condyles. Even though the location of the sample was marked, it was hard to see and reach the back of the Instron hydraulic testing machine since it was too close to the wall. There is a high possibility that there was an error adjusting the sample at the same place after the fixation that caused the pressures at medial condyle to decrease and lateral to increase. Better results could be generated if there is enough space to reach the sample from all directions.

Sawbone #3181 had more solid data that led to specific conclusions. In Figure 4, it is noticeable that the overall spectrum of contact pressures of the sample with instrumentation are generally higher than that of the contact pressures of the sample before instrumentation, ignoring values close to 0. In the similar context, contact pressures of the sample after plate removal was higher than the contact pressures of the sample with plate on. Lateral condyle showed the same characteristics since the pressures were higher for the sample with plate compared to that with no instrumentation. Figure 7 demonstrates that the sample with plate removed had higher contact pressures than the sample with plate on. Moreover, results for 2.5 x body weight were consistent. Contact pressure of the sample with plate was clearly much higher than the sample without instrumentation. The differences in the maximum pressures were evident. Contact pressures before instrumentation peaked at 2.52 MPa one time, whereas a lot of the pressures with instrumentation remained in the regions between 3 MPa and 4 MPa. The distribution in Figure 9 shows that after the instrumentation removal, however, the contact pressure increased even more. The lateral condyle contact pressures also had results that were indistinguishable. Contact pressures for the sample at initial state only went up to about 2.71 MPa, when after instrumentation, they appeared to increase up to 4.5 MPa. Figure 11 was ambiguous since the pressures for both conditions seemed to be generally scattered across the whole range from 0 to the maximum pressure. However, two most frequent contact pressures for the sample with plate are smaller than two most frequent contact pressures for the sample with plate removed. This buttresses the result that contact pressure increased with removed plate. Sawbone #3181 was the only sample with data for all three conditions. Overall, for all medial and lateral for both body weight and 2.5 x body weight, the results turned out to be the same. The contact pressures for the sample increased significantly after the plate instrumentation, as expected. But the contact pressures for the sample also increased when the plate was removed. This explains that the contact pressures did not reinstate to original values, but instead increased more. Some sources of error could be damage in sensors. Due to the repeated testing with one sensor, by the time the sample was measured with 2.5 x body weight and plate removed, some parts of the sensor were damaged and did not read pressure at all. Those were disregarded when analyzing data, but this experiment could improve by redoing the process without damaging sensor. This could be done by applying force minimum amount of times. Also, it was hard to keep track of the same area for examining, because the location of the sensor changed each time.

Conclusions

In this study, a sawbone model was used to examine the influence open reduction internal fixation has on knee contact pressures as well as the effect removal of the fixation has on the contact pressures. Although initial contact pressures of four sawbones were measured, data for #3172 and #3181 were only examined because there were experimental data to compare with the control. For sample #3172, peak contact pressures increased in medial condyle and decreased in lateral condyle after fixation. Histograms for #3172 comparing contact pressures before and after fixation showed indistinguishable result as to if the pressure changed after fixation. The outcome could be more distinct if the contact surface area of condyles was more consistent.

Sample #3181 was measured in three conditions: initial, after fixation, and after removal of fixation. For body weight load in medial condyle, there was an increase from 2.4 MPa to 3.48 MPa, and from 3.48 MPa to 4.03 MPa when the plate was instrumented, and when it was removed. Lateral condyle and the results for 2.5 x body weight load demonstrated similar patterns. While the fixation did escalate the stress on knee cartilage pressure as expected, removal of the fixation did not reinstate it to the original value. This could be because the sensor was damaged due to continuously applied force. Also, if the sensor could stay at the same place for every test, the quality of the results could be enhanced.

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