Radiographic and Clinical Changes of the Tibial Tuberosity Following Tibial Plateau Leveling Osteotomy

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ABSTRACT

Objective- To investigate radiographic changes of the tibial tuberosity following Tibial Plateau Leveling Osteotomy (TPLO) surgery and to identify clinical findings and risk factors associated with such changes.

Study Design- Retrospective study.

Sample population- 186 client-owned dogs comprising 219 stifles that underwent TPLO surgery.

Methods- Patient data surveyed included radiographic changes of the tibial tuberosity during reexamination, age, body weight, whether unilateral or single session bilateral surgery had been performed, location of the anti-rotational pin, approximate tibial tuberosity area, and approximate average tibial tuberosity width.

Results- Fracture with resulting caudal displacement of the proximal tibial tuberosity (3 of 219 or 1.4%) occurred less frequently than non-displaced tibial tuberosity fractures (16 of 219 or 7.3%). Age, weight, average tibial tuberosity width , location of the anti-rotational pin, and single session bilateral surgery were identified as risks factors for the non-displaced fracture. Weight divided by the square of the average tibial tuberosity width, interpreted as an indicator of the stress on the tibial tuberosity, may be a stronger risk factor than either weight or average tibial tuberosity width alone.

Conclusions- Dogs undergoing single session bilateral TPLO surgery are clearly at greater risk for developing the non-displaced tibial tuberosity fracture. The statistical significance of the other risk factors is less clear. The non-displaced tibial tuberosity fracture does not appear to adversely affect outcome or lead to tibial tuberosity avulsion. Significant risk factors for fracture of the proximal tibial tuberosity with caudal displacement are unknown, but placement of the anti-rotational pin distal to the insertion of the straight patellar tendon may weaken the bone.

Clinical Relevance- Factors including age, weight, tibial tuberosity thickness, and conditions which may enhance strain on the tibial tuberosity, such as single session bilateral procedures, may increase the risk of fractures.

INTRODUCTION

Cranial cruciate ligament (CrCL) rupture is a common orthopedic problem in dogs. Tibial Plateau Leveling Osteotomy (TPLO) is a surgical technique that treats CrCL disease by providing functional stability of the stifle joint during weight bearing by decreasing cranial tibial thrust.[1-3] While the TPLO technique has increased in popularity, few reports document postoperative findings or expectations.

One reported post-operative complication of TPLO surgery is avulsion of the tibial tuberosity.[4-6] Tibial tuberosities cut thin during the osteotomy or tibial plateaus that require a large amount of rotation for leveling may produce a greater risk for avulsion.[4] There have been few reports describing the frequency at which tibial tuberosity avulsions occur and none that specify risk factors which may lead to fracture and avulsion.

In two recent retrospective studies of TPLO surgeries, minimally displaced fractures of the tibial tuberosity occurred in 4% and 3.1% of the patients.[5, 6] Nine of the 14 cases in the first report had no acute exacerbation of lameness, and the fracture was considered an incidental finding.[5] The six cases reported in the second study healed without specific treatment.[6]

The observation of a radiographic lucency/fracture of the tibial tuberosity in some patients following TPLO surgery has produced questions as to what changes are clinically significant. The purpose of this study was to investigate radiographic changes of the tibial tuberosity following TPLO surgery and to identify clinical findings and risk factors associated with such changes. Our hypothesis was that mechanical characteristics of the tibial tuberosity leading to increased bone stresses are associated with tibial tuberosity fractures following TPLO surgery.

MATERIALS AND METHODS

Medical records of 243 dogs that underwent TPLO surgery between March 2000 and February 2002 were reviewed. Fifty-seven cases were excluded from the study because reevaluation radiographs were not available. The resulting group of 186 dogs included 219 stifles. Twenty-two of the dogs had single session bilateral TPLO surgeries performed. Eleven of the dogs had unilateral TPLO surgeries performed at different times for treatment of sequential cranial cruciate ligament disease.

A tibial plateau leveling osteotomy was performed on every stifle reviewed. All surgeries were performed by one surgeon according to the patented technique as described by Slocum.[4]

Reevaluation radiographs were examined for evidence of radiographic changes in the tibial tuberosity. Additional data surveyed included age (years), body weight at the time of surgery (kg), whether unilateral or single session bilateral surgery had been performed, and the location of the anti-rotational pin.

Immediate post-operative lateral radiographic views of each hind limb from the hock to the stifle were examined in order to derive relevant structural characteristics of the tibial tuberosity. One surgeon identified each of the anatomic landmarks of the tibia used to define the long axis of the tibia (x-axis). The x-axis was the line drawn along the tibial long axis, proximally passing through a point that divided the medial and lateral intercondylar tubercles and a point distally passing through the center of the talus. The boundaries of the tibial tuberosity were then defined as follows (Fig 1). First, a line representing the y-axis at the distal most point of the osteotomy was drawn perpendicular to the tibial long axis. Next, the cranial boundary of the tibial tuberosity was defined as the cranial surface of the tibial tuberosity (line f) and the caudal boundary of the tibial tuberosity was defined as the radial osteotomy surface (line g) (Fig 1). The y-axis was perpendicular to the tibial x-axis, therefore determining the area bounded by the y-axis, f, and g (the tibial tuberosity), reduced to finding the area under the curves f and g and then taking the difference (Fig 2).

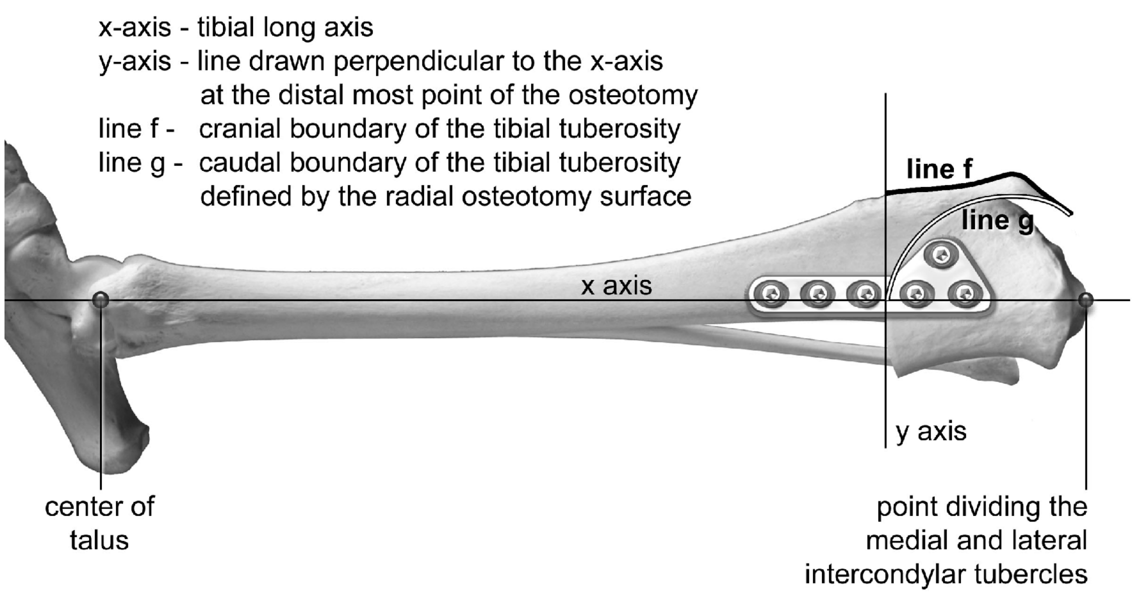

Figure 1. Defining the Boundaries of the Tibial Tuberosity

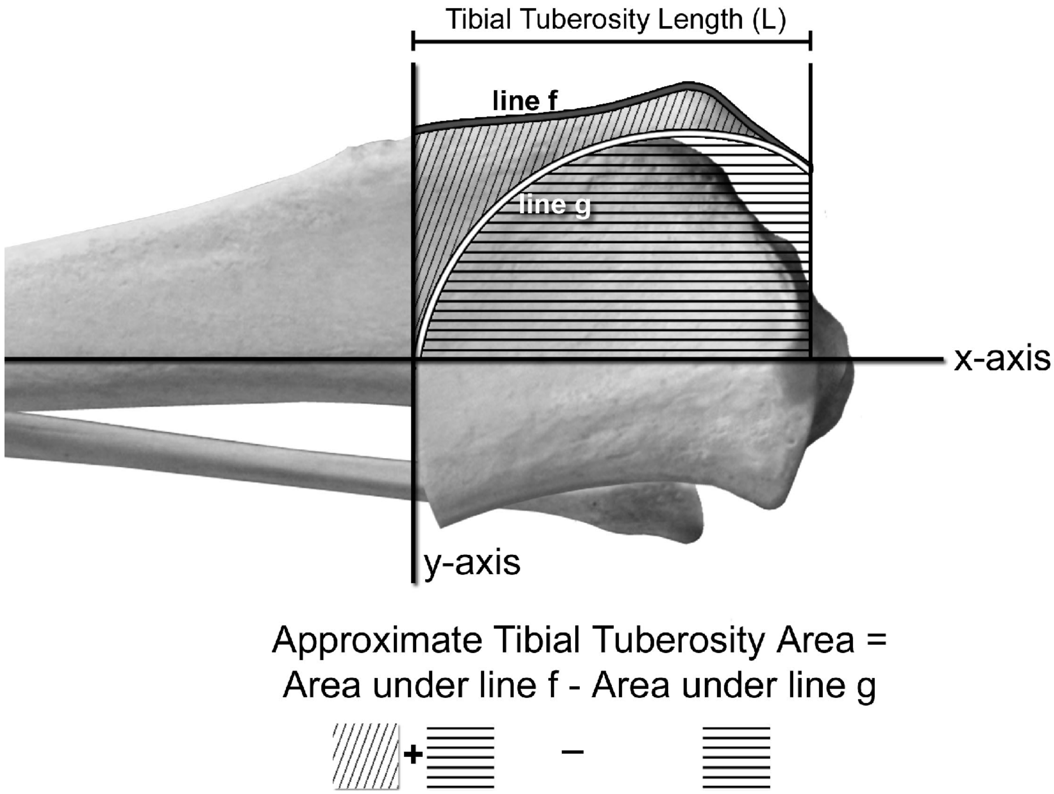

Figure 2. Measuring the Tibial Tuberosity

The trapezoid rule was used to approximate these areas. The length of the tibial tuberosity was defined as the distance between the proximal most aspect of the tibial tuberosity and the distal most aspect of the radial osteotomy. The approximate average tibial tuberosity width was determined by dividing the approximate tibial tuberosity area by the length of the tibial tuberosity.

The curves f and g were determined by superimposing graphing paper with 1 mm intervals (National Brand Engineering Forms, 10 millimeters to the centimeter) over the immediate post-operative radiographs. The tibial tuberosity was then traced using an ultra fine point 1 mm permanent marker. Graph points were recorded at 1 mm intervals for both the cranial boundary (line f) and the caudal boundary of the tibial tuberosity (line g).

Radiographs provide only two-dimensional information about the tibial tuberosity. Given the stress on the tibial tuberosity generated by tension on the patellar ligament, the average cross-sectional area perpendicular to the area measured above (i.e. going into the radiograph) is a more relevant quantity. Intuitively, the average cross-sectional area is the average thickness of the tibial tuberosity. The only information in the radiograph on the cross-sectional area is the average tibial tuberosity width. Assuming the tibial tuberosity is some part of the solid of revolution with radius equal to the tibial tuberosity width, a simple approximation to the average cross-sectional area is C·width^2, where C is some constant incorporating π and the fraction of the solid of revolution constituting the tibial tuberosity, assumed to be roughly the same for all dogs. The true stress on the tibial tuberosity at any moment would clearly be complex to measure or model. A reasonable indicator of this stress would be (D·weight)/(C·width^2) where D is some fraction of the gravitational acceleration. Hence, in addition to the structural features measured directly from the radiographs (length, area, and average width) we will also consider the derived stress indicator weight/width^2. The reason is that, if the hypothesis that bone stresses are responsible for the non-displaced fracture is correct, the directly measured features may have little significance when considered individually. Put more simply, the thinness of the tibial tuberosity, if it is a factor, clearly needs to be measured relative to the size of the dog.

Sources of uncertainty in the geometric quantities describing the tibial tuberosity include inconsistency in radiographic technique, small errors in the x and y coordinates used in the trapezoidal rule, approximation error of the trapezoidal rule, and non-uniformity of the tibial tuberosity (i.e the extent to which it is not a solid of revolution with radius=width). None of these sources of uncertainty can be quantified precisely, however, a reasonable attempt at minimizing these errors was made by including a large number of points in the trapezoid rule, using a fine point marker on finely graded graph paper, and positioning the dog leg consistently.

Statistical Analysis

The end points of this study were whether radiographic changes (fracture and caudal rotation of the proximal tibial tuberosity or non-displaced fracture of the tibial tuberosity) were seen in the reevaluation radiographs prior to starting rehabilitation. Logistic regression was applied to analyze the data set and assess the risk factors for these end points using PROC LOGISTIC (SAS, SAS Institute Inc, Cary, NC). Initially, the following criteria were identified as possible risk factors for fracture of the tibial tuberosity: age, body weight, whether unilateral or single session bilateral surgery had been performed, location of the anti-rotational pin, approximate tibial tuberosity area, and approximate average tibial tuberosity width.

Model selection was performed using a stepwise selection technique and validated using forward and backward selection. Two-way interactions were checked with the resulting models, with the hierarchy principle enforced except as discussed below. In stepwise and backward selection mode, the Wald statistic (ratio of the regression coefficient to the standard error of the coefficient) was used to measure statistical significance; risk factors with a Wald test score of less than 0.05 were removed from the model. In forward selection, the score statistic was used with a value of 0.05 required for entry into the model. In a separate analysis we replaced weight and width with the stress indicator derived above, weight/width^2, and repeated the selection procedures above.

RESULTS

Two radiographic changes were seen in the tibial tuberosity following TPLO surgery. Fracture and subsequent caudal displacement of the proximal tibial tuberosity with the tibial plateau (3 of 219 or 1.4%) occurred less frequently than non-displaced tibial tuberosity fractures (16 of 219 or 7.3%). The clinical findings associated with each differed greatly.

Cases with caudal displacement of the fractured tibial tuberosity were readmitted to the hospital within the first two weeks following surgery for an acute exacerbation of lameness. Physical examination findings included marked lameness, joint effusion, soft-tissue swelling, and bruising of the proximal tibia. Of the three stifles with this complication, two belonged to a grossly obese dog that had undergone single session bilateral TPLO surgery.

Radiographic findings in these cases included caudal displacement of the fractured proximal tibial tuberosity and caudal rotation of the proximal osteotomy segment resulting in an increased tibial plateau angle. The osteotomy gap between the fractured proximal tibial tuberosity and the proximal osteotomy segment was unchanged, hence there was no displacement of the proximal tibial tuberosity relative to the proximal osteotomy segment (Fig 3). Each of these cases had anti-rotational pins placed through the mid-section of the tibial tuberosity, at the same level that the fracture occurred. Due to the small number of cases with this complication, statistically significant risks factors could not be determined.

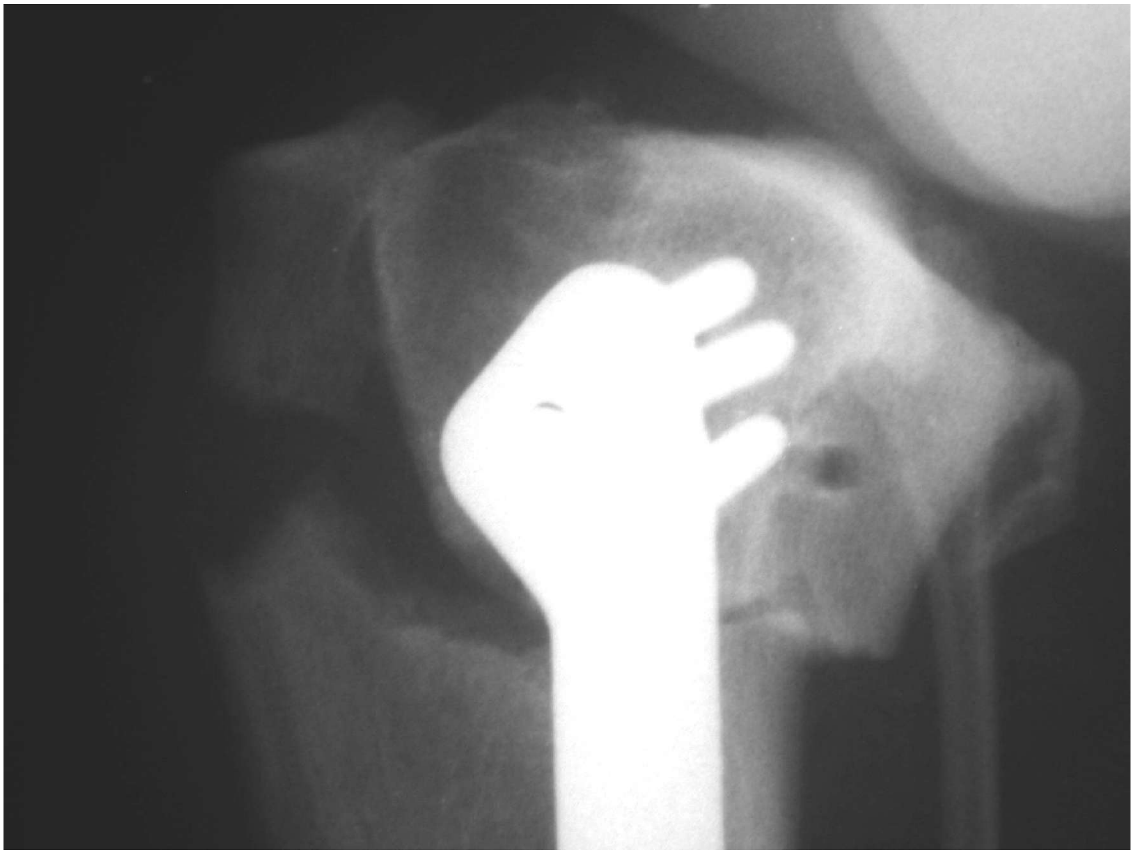

Figure 3. Caudally Displaced Tibial Tuberosity Fracture with Concurrent Caudal Rotation of the Proximal Osteotomy Segment

Non-displaced tibial tuberosity fractures were seen in 16 cases. In each case, radiographs were taken during a scheduled 6 or 8-week reevaluation appointment and none of these cases presented for an acute exacerbation of lameness. The fracture site was approximately one-half way between the proximal most aspect of the tibial tuberosity and the distal most aspect of the osteotomy. Slight obliquity of the fracture was seen with a craniodistal to caudoproximal orientation (Fig 4). The length of the fracture spanned the entire tibial tuberosity width on lateral radiographic projection. The width of the fracture line ranged from 1 to 5 millimeters, but no displacement of the tibial tuberosity or patella alta was observed. No clinical signs were associated with these findings. In all cases, findings were deemed incidental and normal post-operative rehabilitation was begun.

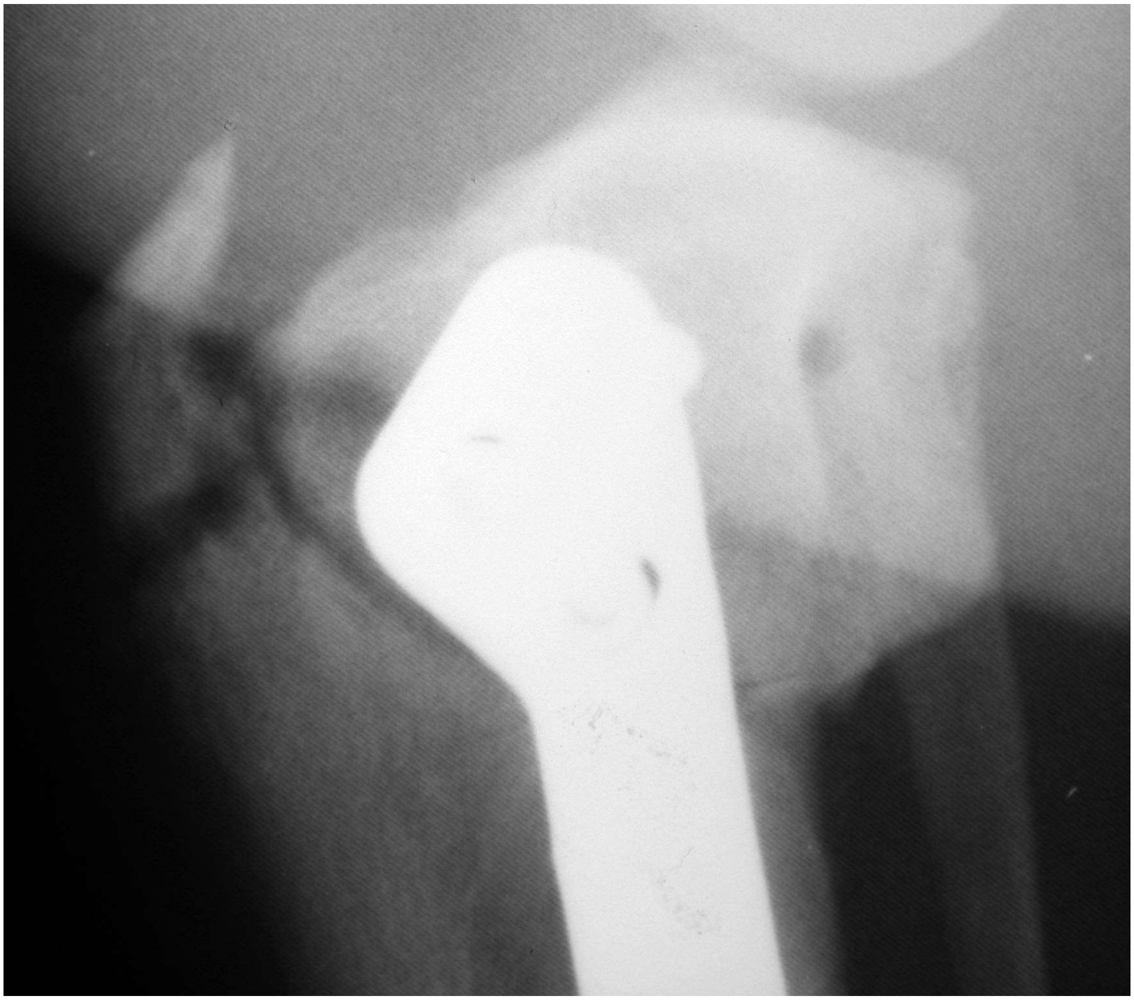

Figure 4. Non-Displaced Tibial Tuberosity Fracture

The stepwise selection procedure identified single session bilateral TPLO surgery, age, weight, and the approximate average tibial tuberosity width as risk factors for the non-displaced tibial tuberosity fracture occurring. Backward selection identified the same set of risk factors while forward selection procedure also identified pin placement as a statistically significant risk factor. We chose to include the pin placement in the model since it appeared to have some effect. No statistically significant interactions were identified by any of the selection procedures while enforcing the model hierarchy. The model parameters, Wald score p-values, standard errors, and 95% confidence intervals are presented in table 1. Some sample odds ratios representing the increase in risk predicted by the model for several different changes in risk factors is provided along with 95% confidence intervals on these odds ratios is given in table 2 . For example, the model predicts a 2.63 fold in crease in the risk of tibial tuberosity fracture for a 4 year increase in age.

In light of the significance of weight and the tibial tuberosity width as risk factors, one possible physiological cause of the non-displaced tibial tuberosity fracture is stress on the tibial tuberosity via the patellar ligament. As discussed above, a more appropriate risk factor might then be an approximation of the average and/or peak stress on the tibial tuberosity. The approximation of this stress discussed above would be proportional to weight/width^2. This new variable is an interaction between the initial risk factors above. Since it has an independent physical significance, however, the

Term	Estimate	Standard Error	Wald p-value	Confidence Interval
Intercept	-3.60	1.80	0.046	-7.13, -0.06
pin	1.17	0.63	0.064	-0.07, 2.40
age	0.24	0.12	0.046	0.004, 0.48
width	-0.43	0.18	0.014	-0.78, -0.09
weight	0.063	0.024	0.009	0.016, 0.11
bilateral	2.45	0.71	0.000	1.26, 3.63

Table 1. Model Parameters (Hierarchy PreservingModel)

Effect	Unit	Odds Ratio	Confidence Interval
width	-2	2.38	1.25, 5.05
width	-4	5.66	1.55, 25.48
width	-6	13.47	1.93, 128.6
age	2	1.62	1.02, 2.66
age	4	2.63	1.03, 7.07
age	8	6.94	1.06, 50.04
bilateral	1	11.58	3.67, 41.43
weight	5	1.37	1.09, 1.77
weight	10	1.87	1.19, 3.12
weight	20	3.51	1.42, 9.72
weight	40	12.35	2.00, 94.58
pin	1	3.22	0.93, 11.07

Table 2. Odds Ratios (Hierarchy Preserving Model)

hierarchy principle in the selection procedures was not enforced. Replacing weight and width by weight/width^2 and running the selection procedure above yields the risk factors weight/width^2, pin placement, and bilateral surgery as risk factors. Tables 3 and 4 provide the same information for the stress-based model as given previously.

The approximate tibial tuberosity area was not a statistically significant risk factor for the non-displaced tibial tuberosity fracture. Tibial tuberosity avulsion, as classically described, appears to be a rare complication of TPLO surgery but was not reported in the study.

Term	Estimate	Standard Error	Wald p-value	Confidence Interval
intercept	-4.80	0.80	0.0001	-6.59, -3.39
weight/width^2	2.50	1.15	0.029	0.43, 5.06
pin	1.39	0.57	0.015	0.27, 2.52
bilateral	2.19	0.56	0.000	1.08, 3.30

Table 3. Model Parameters (Stress-based Model)

Effect	Unit	Odds Ratio	Confidence Interval
weight/width^2	0.2	1.65	1.05, 2.58
weight/width^2	0.4	2.72	1.11, 6.68
weight/width^2	0.8	7.39	1.23, 27.08
pin	1	4.03	1.30, 12.47
bilateral	1	8.93	2.95, 27.08

Table 4. Odds Ratios (Stress-based Model)

DISCUSSION

Two types of fractures were seen in the tibial tuberosity following TPLO surgery. We observed a caudally displaced fracture of the proximal tibial tuberosity with concurrent caudal rotation of the proximal osteotomy segment, a finding that has not been previously reported. In each case the clinical findings were typical of bone fracture: acute exacerbation of lameness, pain, soft-tissue swelling, and bruising.

Placement of the anti-rotational pin at the site of the fracture may weaken the bone allowing for fracture to occur. Implant loosening was confirmed during revision of each TPLO. These cases were repaired with open reduction and internal fixation following the removal and replacement of the TPLO plate and screws and the placement of a tension band wire in the tibial tuberosity. Each fracture healed and limb function following rehabilitation was good.

It is unclear whether fracture of the tibial tuberosity precedes caudal rotation of the plateau or not. We feel that it is more likely that fracture fixation failure of the osteotomy resulted in caudal rotation of the tibial plateau, and that the proximal tibial tuberosity fractured as a result. Two of the three tibial plateaus having this complication belonged to the same patient who was grossly obese and had undergone single session bilateral TPLO surgery. Placement of the anti-rotational pin proximal to the Sharpey's fibers of the straight patella ligament, the addition of a second TPLO bone plate, and/or staged unilateral TPLO surgeries may prevent such complications.

The second type of fracture, a non-displaced tibial tuberosity fracture, should not be confused with an avulsion fracture. Whether this radiographic finding is a true fracture or an osseous lucency created by bony remodeling is not known. A true fracture would be expected to displace proximally due to patellar ligament tension and be associated with clinical signs. An alternative explanation may be osseous resorption of the tibial tuberosity resulting in a focal lucency without an actual fracture occurring.

Osseous resorption may be caused by thermal necrosis during the osteotomy, stress remodeling due to changes in normal strain on the tibial tuberosity, or vascular compromise secondary to soft tissue dissection. It is unknown why proximal displacement of the tibial tuberosity did not occur in these cases. An incomplete fracture and/or strong soft tissue attachments may prevent proximal displacement.

Assessment of weight bearing by physical examination for each of these dogs was determined to be appropriate for the stage of recovery. It is possible that a more objective assessment of weight bearing such as force plate analysis may identify decreased weight bearing in these patients, or that clinical signs associated with fracture had resolved by the time of our reevaluation.

Possible causes of the non-displaced tibial tuberosity fracture include excessive pull from the quadriceps mechanism, vascular compromise secondary to soft tissue dissection, osteotomy gap stress, and thermal damage that occurred during the osteotomy. The data and statistical models in this study provide evidence that the non-displaced fracture may be due to stress on the tibial tuberosity during recovery. Dogs undergoing single session bilateral TPLO surgery must bear weight on the affected limbs following surgery, and the statistical models predicted 8.5 and 9.6 fold increases in risk for these dogs. Indeed 10 of the 19 cases with non-displaced fracture underwent bilateral surgery while there were only 44 bilateral cases among the 219 cases in the study. One dog that underwent bilateral single session TPLO surgery developed the lucency on one tibial tuberosity but not the other. The tibial tuberosity with the lucency had a significantly smaller approximate average tibial tuberosity width. Of the remaining 9 non-displaced fracture cases with unilateral surgeries, 6 had weight/width^2 ratios of larger than the mean weight/width^2 of 0.47 (standard deviation 0.18) with a mean weight/width^2 for these 6 cases of 0.70 (standard deviation 0.14). Of the remaining 3 cases, 2 occurred in dogs aged 10 and 11 years. Likewise, the logistic regression analysis suggests a correlation between the non-displaced fracture and weight, tibial tuberosity width (or weight/width^2) and age. Other contributing factors to a stress-related fracture could be age-related degradation of the bone strength, faster healing in younger dogs, and weakness due to thermal damage. Immature animals are known to have faster bone healing when compared to a mature dog, but the differences in healing between mature and geriatric patients is not known. Thermal damage and/or vascular compromise could also have been a direct mechanism for the non-displaced fracture but none of the data collected contain any information on such processes.

In 5 of the 16 cases with the lucency, the anti-rotational pin was placed in the mid-region of the tibial tuberosity. In all of these cases the radiographic lucency occurred proximal to the pin tract and a clear distinction between the two was present. Only in the backward selection procedure was the location of the pin identified as a risks factor for fracture, but the authors recommend placement of the anti-rotational pin proximal to the insertion of the patellar ligament on the tibial tuberosity (Sharpey's fibers).

Variations in tibial tuberosity length could explain why tibial tuberosity area was not a risk factor. Based on the technique that we used to approximate area, it was possible for a long thin tibial tuberosity to have an equal area to that of a short thick tibial tuberosity. Attempts to identify a "minimally acceptable tibial tuberosity width" were unsuccessful, however the data supports the perception that a thicker tuberosity is more resistant to fracture.

CONCLUSIONS

Factors including age, weight, tibial tuberosity width, and conditions which may enhance strain on the tibial tuberosity, such as single session bilateral procedures and pin placement, may increase the risk of fractures. Non-displaced tibial tuberosity fractures do not appear to adversely affect outcome and do not require surgical fixation.

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