Biomechanical properties of an implant designed to stabilize the coxofemoral joint following luxation show dissimilarity to the native ligament of the head of the femur in cattle

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OBJECTIVE
To improve upon the toggle-pin implant construction and develop a repeatable surgical technique to achieve coxofemoral stabilization in mature cattle.

ANIMALS
9 adult bovine cadaveric coxofemoral joints, 8 bovine femurs, 2 beef calf cadavers.

PROCEDURES
Ultimate tensile strength and elongation at failure were measured for the native ligament of the head of the femur (LOHOF) harvested up to 48 hours after death, and the prosthetic prototype utilizing stainless-steel cable and prosthetic prototype utilizing nylon leader line were compared. Bovine femurs were utilized to locate the ideal and repeatable trajectory of the prosthetic ligament to exit at the origin of the LOHOF. Using fluoroscopy, thawed calf cadavers with radiopaque markers placed at sites of origin and insertion of the LOHOF were positioned to assess limb angle to maximize joint isometry resulting in the ideal placement of the LOHOF prosthesis. The study was performed between February 1, 2020, and December 1, 2021.

RESULTS
The stainless-steel prototype had a significantly higher ultimate tensile strength and significantly decreased elongation at failure when compared to the LOHOF, while the nylon-based prototype had significantly decreased tensile strength and elongation at failure compared to the LOHOF. Therefore, neither prototypes were biomechanically similar to LOHOF.

CLINICAL RELEVANCE
The stainless-steel prosthetic prototype shows promise to provide superior stabilization to the luxated coxofemoral joint.

Coxofemoral or hip joint luxation is among the most common causes of orthopedic injury in the bovine proximal hindlimb and the second most common luxation in cattle and buffalo. The incidence of luxation is estimated at 1 per 1,000 dairy cows per year with a greater number in Holstein-Friesian and Friesian Jersey cross cows. Coxofemoral luxation is potentially underdiagnosed; a recent study suggests upper limb lameness accounts for 36% (901/2,532) in feedlot cattle, refuting older dogma that approximately 90% (8,105-foot lesions/9,178 total lameness cases) of bovine lameness localizes to the distal limb.

Stability of the coxofemoral joint relies on many fibrous structures including the transverse acetabular ligament, labrum acetabular, thick joint capsule, and the ligament of the head of the femur (LOHOF). Additionally, the contribution of surrounding muscle mass formed by the gluteal muscles and deep hip joint muscles should not be underemphasized.

Anatomic differences predispose cattle to luxation of their coxofemoral joint; compared to horses, cattle have a shallower acetabulum, notches in the acetabular ring margin, a smaller femoral head, and lack an accessory ligament, which provides additional stabilization to the hip joint of the horse. These characteristics lead to a greater likelihood of coxofemoral luxation in the cow despite the substantial muscle mass surrounding the joint.

Coxofemoral luxation is most commonly the result of a traumatic event and is more commonly seen in cows compared to bulls. Nutritional imbalances, weakness secondary to nerve dysfunction,
postpartum, pelvic ligamentous laxity from high estrogen concentrations, and mounting behavior from bulls during breeding are among some of the causes leading to a traumatic luxation.4

Clinical signs, physical examination, and radiographic imaging are typically sufficient for diagnosis. Substantial challenges lie in the treatment and management of adult cattle with coxofemoral luxation. If the coxofemoral luxation is not reduced, cattle may form a pseudoarthrosis, but patients typically will continue to be severely lame or unable to rise, leading to substantial animal welfare concerns and economic losses from decreased productivity.10–12

Nonsurgical reduction is recommended as the first line of treatment and should be attempted before any surgical efforts are pursued. Reduction within 12 to 24 hours after luxation has been associated with a better prognosis for return to function with success rates ranging from 43% (20/47 cattle)3 to 75% (30/40 cattle)12 of cases.4,13,15 After luxation, the acetabulum fills with a fibrin clot that becomes firm and can prevent the femoral head from reducing after an extended period.16 As a result, relaxation is common following reduction.

Numerous surgical techniques have been described to repair coxofemoral luxation including open reduction with acetabular clearance,4,8,17 capsular repair,4 femoral head ostectomy,18 ligamentous graft,19,20 and toggle pin stabilization (Shaver EM, AGR ENG, The Ohio State University, unpublished data, 1984).21,22 Toggle pin stabilization is a technique where a toggle suture (also termed bar suture or shuttle suture) functions as a prosthetic LOHOF. This technique is of interest because of a low relaxation rate reported in small animals (approx 5% in dogs).23 A stainless-steel toggle pin implant for cattle was constructed by Adams et al21 in 1957 with a reported short-term success rate of 70% (7/10 cattle) in cattle. In 1990, a prosthetic toggle pin implant similarly fabricated from a nylon leader line and stainless-steel Steinmann pins were used to repair experimentally created coxofemoral luxations. Two of 6 animals reportedly recovered; however, the trial was performed over a short duration.22 The strength of the toggle pin implant and the biomechanical characteristics of the LOHOF as well as the ideal placement for the implant were not investigated in either study.21,22

The overarching goals of the study presented here were to design an improved toggle pin implant for bovine coxofemoral luxation repair, determine its potential effectiveness for stabilization of the adult bovine hip joint using an ex vivo model, and describe a method for implantation. We determined the suitability of 2 toggle pin prosthetic prototypes by comparing their biomechanical characteristics, ultimate tensile strength (UTS) and their elongation at failure (EAF), to those of the native, bovine LOHOF. UTS was defined as a measure of the maximum tensile load prior to failure while EAF a measurement of material ductility. Additionally, we investigated the utility of using palpable boney landmarks and limb positioning for repeated isometric placement of the toggle pin prosthetic in cattle.

We hypothesized a stainless-steel toggle pin implant would be superior to one utilizing nylon and would have no significant difference in UTS or EAF compared to the native ligament. We also hypothesized that the palpable lateral femoral epicondyle and the greater trochanter could be used as anatomic landmarks and the limb would need to be held in abduction to predictably place toggles in an isometric location.

Materials and Methods

Subjects

LOHOF biomechanical testing cadavers

Nine coxofemoral joints were collected between February 1, 2020, and December 1, 2021 from 9 adult cattle euthanized for reasons unrelated to the hip joint. The LOHOF was harvested up to 48 hours after death. The body weight of these cattle (posteuthanasia) ranged between 336 and 768 kilograms. An institutional animal care and use committee approval was not required as these cattle were euthanized for reasons unrelated to this study. The os coxae was freed from the remaining pelvis by transection mid ilium, ischium, and pubis, and the femur was transected at the proximal diaphysis. All soft tissues except for the LOHOF were removed. The soft tissue removal was performed in a standard large animal operating suite with an ambient temperature of approximately 20 °C. Following removal of the soft tissues, the specimens were stored at −18 °C.

Femoral isometric testing cadavers

Eight adult cattle femurs marketed for canine amusement were purchased (Amazon.com). The femurs were stored in a storage facility at approximately 20 °C until use on October 18, 2021.

Calf isometric testing cadavers

Two newborn calves that died of causes unrelated to the coxofemoral joint disease were stored at −18 °C directly after death until use. The cadavers were thawed started 24 hours before use to 20 °C and evaluated during the week of March 28, 2021. Institutional animal care and use committee approval was not required as these calves were deceased for reasons unrelated to this study. Evaluation was performed in a standard large animal operating suite with an ambient temperature of approximately 20 °C.

LOHOF biomechanical testing

All 9 coxofemoral joints were thawed for a continuous 24-hour period prior to testing. An octagonal apparatus was constructed to rigidly fix the os coxae to the base of a servohydraulic materials test frame using 0.25-inch (6.4 mm) stainless steel threaded rods (Bionix 858; MTS Corp, Supplementary Figure S1). Three tunnels made with a 6.4-mm carbide drill bit were drilled into the diaphyseal and metaphyseal regions of the femur and fixed to an actuator of the same load frame for distraction. Tensile forces were applied under displacement control set at 0.5 mm/s with loading and displacement
values recorded every 0.025 mm. Peak load to failure and mode of failure were noted.

**Femoral isometric testing**

Eight adult bovine femurs were utilized to measure ideal toggle pin implant placement. The distance between the most proximal aspect of the greater trochanter to the most lateral aspect of the lateral femoral epicondyle was measured in centimeters for each femur (Figure 1). A drill bit was then placed so that the point was 90° from the lateral aspect of the femur it was contacting and the bit traveled axially down the femoral neck and exited at the point of the insertion of the LOHOF. The length from the proximal greater trochanter to the point of entry of this hole (D) laterally was then measured.

![Figure 1](image1.png)

**Calf isometric testing**

Both calves were thawed for a continuous 24-hour period prior to testing and placed in right lateral recumbency on a large animal surgery table elevated 2 feet above the floor (Figure 2). The left or upmost coxofemoral joint was accessed via minimal dissection, and the LOHOF was then transected. Stainless-steel ball bearings (4.5 mm in diameter) were pressed into the origin and insertion sites for the LOHOF. The calf’s right greater trochanter was positioned over a marker on the surgical table that was in vertical alignment with a vertical laser. The calf’s left greater trochanter was aligned with this vertical laser so that a line intersecting the calf’s 2 trochanters was perpendicular to the floor. The ball bearings were visualized using fluoroscopy, and the leg was manipulated to determine the leg position that minimized the distance between the ball bearings (origin and insertion sites from the LOHOF). With the leg...
The length of the hindlimb from the greater trochanter to the tip of the toe was measured and recorded as “x.” Using a 3-foot (0.92 m) level, a level line was projected from the tip of the toe proximally so that it bisected the vertical laser. The distance along this level line from the tip of the toe to the intersection of the vertical laser was measured and recorded as “x.” The line level and the vertical laser formed a right angle, and the resultant triangle was a right triangle. The vertical distance parallel to the laser line from the level to the tip of the toe, labeled as “y” was calculated using the Pythagorean theorem. Using these distance measurements, the ideal angle of adduction or abduction, θ, was calculated using trigonometric functions.

\[ \cos \theta = \frac{x}{r} \]

**Prosthesis biomechanical testing**

The artificial ligament or toggle pin implant consisted of a rigid shaft, a flexible “ligamentous” portion, and a rigid toggle. The materials used need to be able to be implantable and withstand certain strength requirements. The shaft design had to be devised to allow for an adjustable range of lengths to fit differing femoral neck sizes and be < 13 mm in diameter as any shaft greater would structurally weaken the femoral neck (Shaver EM, AGR ENG, The Ohio State University, unpublished data, 1984). The prosthetic ligament, in addition to meeting the shaft requirements, needed to withstand normal and abnormal stresses on the hip joint as well as permit a normal range of motion. The toggle construction needed to meet 3 additional criteria: be able to fit through a predrilled hole in the acetabulum, be able to sufficiently resist the loading stress when opened onto the medial acetabulum, and a rigid toggle. The materials used need to be able to be implantable and withstand certain strength requirements. The shaft design had to be devised to allow for an adjustable range of lengths to fit differing femoral neck sizes and be < 13 mm in diameter as any shaft greater would structurally weaken the femoral neck (Shaver EM, AGR ENG, The Ohio State University, unpublished data, 1984). The toggle design was based on prior work. The toggle design was based on prior work. The other 5 artificial ligaments were constructed as described in Figure 3. A hole would be drilled from the lateral femur, down the neck, through the head and acetabulum. The apparatus would then be secured tightly by placing a washer and 2 nuts on the lateral side of the femur and tightening them down the threaded portion of the shaft. The excess shaft could then be cut away.

Ten prototype prosthetic ligaments were constructed (Figure 3). Five were constructed with a 2.4-mm uncoated 316 stainless-steel cable cut to be 110 mm long. The shaft was designed using a 4.8-mm diameter, 190.5-mm-long 316 stainless-steel, fully threaded rod with a thread pitch of 0.794 mm. One end had 51 mm of threads removed externally creating a 3.6-mm diameter, a 2.5-mm hole bored down the center over this distance, and the hold threaded with a 0.635-mm pitch tap. Removing the thread allowed for appropriate crimping of the rod once the cable was inserted into the hole while threading this center hole provided for interdigitations to better grip the prosthetic ligament following insertion. The rod was crimped onto the cable 6 times by placing crimping die into a hydraulic press to distribute pullout forces along the interface between the rod and cable. The “toggle” portion of the prosthetic was constructed from 316 stainless-steel rod cut to be 30 mm in length, with a 2.5-mm central bore for the entire length of the toggle that was then tapped with a 0.635-mm pitch tap. Half of the outer cylinder was removed back at a length of 15 mm. The free end of the cable was then inserted into the full length of the toggle and crimped twice as previously described.

The other 5 artificial ligaments were constructed in a similar fashion. Lengths remained the same; however, a 6.35-mm diameter 316 stainless-steel, fully threaded rod with a pitch of 0.907 mm was used to construct the shaft. After stripping the threads from the 51-mm portion, the new outer diameter for this length was 4.6 mm. A 2.9-mm hole was bored down the center of this length, a 0.787-mm pitch tap was utilized to thread the inside of the bored hole.
800-lb test monofilament nylon leader line was used to construct the prosthetic ligament and 6.35-mm 316 stainless-steel rod for the toggle. The toggle was also tapped with a 0.787-mm pitch tap to provide for interdigitations to better grip the prosthetic ligament following insertion.

The prosthetic ligaments were fixed to an actuator of the same load frame for distraction. Tensile forces were applied under displacement control set at 0.5 mm/s with loading and displacement values recorded every 0.025 mm. Peak load to failure and mode of failure were noted.

**Statistical analysis**

An online power analysis was used to determine sample size. The settings included comparing k means: 1-way ANOVA pairwise, 2-sided equality with power set at 0.8, mean 1 set at 6,500 N, mean 2 set at 4,500 N, and SD set at 1,000 N. This was based on prior work done on cranial cruciate ligaments in cattle. All data collected were analyzed using a commercial software program. Ligament, stainless-steel, and polymer implant data were checked for normality using the Shapiro-Wilk test with homogeneity set at > 0.05. If the null hypothesis for UTS for the ligament, stainless-steel, and polymer implant data were rejected and was proven to be nonhomogeneous, mean UTS and elongation at failure of the ligament and the stainless-steel and polymer implants would be compared using a 1-way ANOVA with significance set at > 0.05. If the null hypothesis for UTS for the ligament, stainless-steel, and polymer implant data were rejected and was proven to be nonhomogeneous, mean UTS and elongation at failure of the ligament and the stainless-steel and polymer implants would be compared using a 1-way ANOVA with significance set at > 0.05. Post hoc tests were performed using the Welch and Games-Howell post hoc tests. Body weight and ligament UTS and elongation at failure were compared using Pearson correlation coefficient with a 2-tailed test of significance set at > 0.05. Length from the greater trochanter to the drill point using Pearson correlation coefficient with a 2-tailed test of significance set at > 0.05. Additionally, there was no statistically significant correlation between age of cattle and UTS (P = .990) and elongation at failure (P = .688). The UTS was also not found to be correlated with the ligament’s elongation at failure (P = .501).

The 5 stainless-steel toggle pin implants were evaluated. The UTS was 2,245 ± 571 N, and the mean elongation at failure was measured to be 15 ± 4.6 mm. For all 5 artificial ligaments, the stainless-steel cable failed by slipping from the threaded stainless-steel pin. The 5 nylon leader line toggle pin implants had a UTS of 385 ± 93 N with a mean elongation at failure measuring 12 ± 2.5 mm. Four of the 5 artificial ligaments failed from the nylon leader line slipping from the threaded stainless-steel rod while the fifth implant failed from the toggle slipping off the nylon leader line.

Results of the Shapiro-Wilk test indicated normally distributed data for the UTS for the native bovine LOHOF (P = .371), the prosthetic construct made from stainless-steel cable (P = .183), and the prosthesis made from nylon leader line (P = .438). The mean ± SD UTS was significantly greater for the stainless-steel cable construct (2,245 ± 571 N) versus the native bovine LOHOF (195 ± 423 N) and the nylon leader line construct (385 ± 93 N) and was significantly greater for the native bovine LOHOF versus the nylon leader line construct, as determined by 1-way ANOVA (F = 25.166; P < .001) and confirmed significant from a Welch test (P < .001), which was performed due to the violation of homogeneity (Levene test; W = 5.51; P = .015; Supplementary Figure S2). A Games-Howell post hoc test was run due to the heterogeneity of data and found that the mean ± SD UTS was significantly (P < .001) lower for the nylon leader line versus the native bovine LOHOF and significantly (P = .023 and P = .004, respectively) higher for the stainless-steel cable versus the native bovine LOHOF and nylon leader line. Results for the elongation at failure for the native bovine LOHOF, stainless-steel cable, and the nylon leader line were normally distributed (Shapiro-Wilk test; P = .377, .836, and .387, respectively) and homogenous (Levene test; W = 0.876, P = .435). The mean elongation at failure was significantly (1-way ANOVA; F = 22.259; P < .001) lower for the stainless-steel cable (15 ± 4.6 mm) and nylon leader line (12 ± 2.5 mm) versus the native bovine LOHOF (29 ± 6 mm; Supplementary Figure S3). Using Tukey honestly significant difference post hoc test, the mean elongation at failure for each the stainless-steel cable and nylon leader line was significantly (P < .001) lower than that for the native bovine LOHOF, whereas the mean elongation at failure did not differ (P = .531) between the stainless-steel cable and nylon leader line.

**Results**

**LOHOF biomechanical testing**

Eight of the 9 limbs were obtained from females (Supplementary Table S1). There were 6 different breeds represented in our data, 4 Jersey cross, 2 mixed-breed beef, and 1 of each of the following breeds: Brown Swiss, Polled Hereford, and Charolais.

The mean ± SD body weight and age of the 9 adult cattle were 522.13 ± 172.27 kg and 3.67 ± 1.39 years. The ligaments tested had a mean UTS of 1,195 ± 381 N. Mean ± SD UTS, elongation at failure for each the stainless-steel and polymer implants would be compared using a 1-way ANOVA with significance set at > 0.05. If the null hypothesis for UTS for the ligament, stainless-steel, and polymer implant data were rejected and was proven to be nonhomogeneous, mean UTS and elongation at failure of the ligament and the stainless-steel and polymer implants would be compared using a 1-way ANOVA with significance set at > 0.05. Post hoc tests were performed using the Welch and Games-Howell post hoc tests. Body weight and ligament UTS and elongation at failure were compared using Pearson correlation coefficient with a 2-tailed test of significance set at > 0.05. Length from the greater trochanter to the epicondyle was compared to the length from the greater trochanter to the drill point using Pearson correlation coefficient with a 2-tailed test of significance set at > 0.05.

The mean ± SD UTS was significantly greater for the native bovine LOHOF (195 ± 423 N) and the nylon leader line construct (385 ± 93 N) and was significantly greater for the native bovine LOHOF versus the nylon leader line construct, as determined by 1-way ANOVA (F = 25.166; P < .001) and confirmed significant from a Welch test (P < .001), which was performed due to the violation of homogeneity (Levene test; W = 5.51; P = .015; Supplementary Figure S2). A Games-Howell post hoc test was run due to the heterogeneity of data and found that the mean ± SD UTS was significantly (P < .001) lower for the nylon leader line versus the native bovine LOHOF and significantly (P = .023 and P = .004, respectively) higher for the stainless-steel cable versus the native bovine LOHOF and nylon leader line. Results for the elongation at failure for the native bovine LOHOF, stainless-steel cable, and the nylon leader line were normally distributed (Shapiro-Wilk test; P = .377, .836, and .387, respectively) and homogenous (Levene test; W = 0.876, P = .435). The mean elongation at failure was significantly (1-way ANOVA; F = 22.259; P < .001) lower for the stainless-steel cable (15 ± 4.6 mm) and nylon leader line (12 ± 2.5 mm) versus the native bovine LOHOF (29 ± 6 mm; Supplementary Figure S3). Using Tukey honestly significant difference post hoc test, the mean elongation at failure for each the stainless-steel cable and nylon leader line was significantly (P < .001) lower than that for the native bovine LOHOF, whereas the mean elongation at failure did not differ (P = .531) between the stainless-steel cable and nylon leader line.

**Toggle pin placement location**

The mean length between the greater trochanter and the femoral epicondyles was found to be 32.0 ± 1.67 cm. The distance between D (entry point of drill bit on lateral femur) and the greater trochanter had a mean of 6.75 ± 0.73 cm. The average ratio between
the 2 values was found to be 0.2 (Supplementary Table 2). The correlation between the distance between the greater trochanter and the femoral epicondyle was found to be insignificant when compared to the distance between the greater (P = .460) and point D (P = .251).

**Ideal angle**

The level length was 70.8 cm for the first calf and 68.6 cm for the second calf in the adducted position when the ball bearings placed in the origin and insertion of the LOHOF were properly aligned. The 2 values for leg length of the 2 calves were 71.4 and 73.4 cm, respectively. With 2 values of the right triangle measured, this determined that the approximate angles (θ) for ideal placement of the implant was 7.6° adducted for the first calf and 20.7° adducted for the second calf.

**Discussion**

Established techniques for surgical reduction and stabilization of coxofemoral luxation in mature cattle are lacking. Implant failure, recurrence of luxation, and severe degenerative joint disease are reported complications following treatment of coxofemoral luxation in cattle. Literature in small animals supports the use of toggle implantation for treatment of coxofemoral luxation resulting in high success rates. If a similar technique could be successfully developed for cattle, this would potentially decrease morbidity and production loss associated with this debilitating injury. In this study, we sought to develop a toggle pin implant and test its ex vivo suitability for stabilization of the bovine coxofemoral joint. The first aim of this study was to determine the native strength of the bovine LOHOF. The second aim of the study was to develop 2 toggle pin implant designs and compare their mechanical properties to those of the native bovine LOHOF. A third aim of the study was to develop a technique to place the toggle suture through the bovine coxofemoral joint in an isometric manner.

The hypothesis that the stainless-steel toggle pin implant would be superior to the nylon implant based on statistical similarity to the native ligament was not supported, as the UTS of the implant was greater than that of the LOHOF, and the EAF was lower. Our hypothesis that the greater trochanter and lateral femoral epicondyle could be used as landmarks for isometric toggle placement was also not supported.

To compare biomechanical properties of proposed prosthetic implants to the native LOHOF, we first determined the biomechanical properties of the native LOHOF. Although some of this information has been previously estimated by extrapolating from other ligaments, actual values from testing the LOHOF in cattle have not been established. The UTS of LOHOF was found to be 1,200 N, twice that of the dog and about one-fourth of that of the estimated value using a geometrically similar bovine ligament. To support our findings, it is noted that the reported values of the cranial cruciate ligament of the cow and the dog share the same correlation with the cow being one-half the strength of the dog.

It is, however, possible that our values are falsely low due to our collection and testing techniques. In this study, coxofemoral joints were collected from animals who had died or were euthanized for reasons unrelated to lameness of disease of the coxofemoral joint. The joint specimens were collected at time of necropsy which varied from 1 hour postmortem to 48 hours postmortem. These specimens were also frozen until time of testing. Bovine superficial digital flexor tendon tissue has been shown to have a 6% to 9% decrease in tensile modulus after 1 freeze-thaw cycle thus it is possible our reported bovine LOHOF UTS and EAF values are lower than living tissue.

Additionally, UTS and EAF were determined by constant rate distraction while coxofemoral luxation is typically traumatic in origin. Reportedly, an increased strain rate may lead to a higher UTS and decreased elongation. Despite these caveats, we used a UTS of 1,200 N as our target tensile strength to approximate the ideal prosthetic LOHOF.

Implant material is largely responsible for its biomechanical properties. The implant needs to be comprised of a nonreactive material that is able to be sterilized. Additionally, it needs to be stiff enough to be able to drive through a femoral bone tunnel, yet flexible enough to allow the toggle to turn and engage the acetabulum. Toggle constructs comprised of 2 different biomaterials (stainless steel/nylon) were compared in this study. Stainless steel is strong, generally has low biological reactivity in vivo, and is easily sterilized. The ability to use the stainless steel in a braided cable configuration further increased the strength while providing flexibility. Monofilament nylon has been investigated by one of the authors (AJN) in other bovine ligament replacement applications. Nylon does require chemical sterilization but offers improved flexibility when compared to stainless-steel cable. This flexibility made the toggle easier to rotate, which may provide an increased ease of placement in vivo. Additionally, the use of nylon provides a reduction in implant weight.

This study demonstrated that neither the stainless steel nor nylon-based prosthetics were equivalent to the native LOHOF. The nylon prostheses had a much lower UTS and EAF compared to the native LOHOF and would not be an acceptable implant. The stainless-steel prosthesis’ biomechanical performance would potentially be an acceptable implant prototype for coxofemoral reconstruction. The stainless-steel toggle pin prototype had about twice the UTS as the LOHOF but lower EAF. As mentioned, depending on the method of ligament load and rupture, it may be beneficial for the prosthesis to have a higher UTS. Furthermore, the LOHOF is not the only structure providing stability to the joint. This study did not establish the forces needed to luxate a hip joint in the presence of an intact joint capsule and supporting musculature. It is very likely the forces would be much higher, and a prosthet with a higher UTS would in that case be desirable. The significance of the lower EAF of the stainless-steel implant
compared with the native ligament is not known. It is possible that the increased stiffness of the implant could result in accelerated cycling and failure of the implant. Conversely, greater elongation would result in subluxation of the joint. Further studies focused on cyclic loading of the implant are necessary to determine the impact of the decreased EAF.

Both toggle pin prosthesis prototypes failed at either the prosthetic ligament and toggle interface or prosthetic ligament and pin interface. Thus, proving the need for increased security between the ligament prosthetic and the stainless-steel rods (pin/toggle). In this study, crimping the stainless-steel rods around the prosthetic ligament was utilized to attach the rigid rod to the flexible portion of the prosthesis. Our results show that this attachment point is the weakest part of the prosthesis construct.

One of the aims of this study was to determine the ideal location on the lateral aspect of the femur to begin drilling for placement of the prosthesis. The preliminary data suggest that the ideal placement was approximately 0.2 times or one-fifth of the distance between the greater trochanter and the most lateral point of the lateral epicondyle. The correlation between these 2 points on the femur were not significantly correlated because of a range of negative and positive correlations. Thus, they cannot be recommended as the ideal drill point for toggle pin placement. These data show great variability in the bovine femur. Ultimately supporting the influence many factors have on growth and development including environment, genetics, sex, age, and health of the live cow before collection. Because of this great variability, more data are needed to make a definitive recommendation on surgical placement.

To maximize isometry in placement of the prosthetic toggle, it was also found that the limb should be held slightly adducted during implant placement to minimize the distance between the origin and insertion of the LOHOF. This limb positioning is different than the position of the limb when stabilized in an emher sling, commonly used in calves with coxofemoral luxations postreduction. It is possible that the head of the femur best seats in the acetabulum while the insertion and origin of the ligament are not approximated. It was also possible that the immature bovine skeleton is anatomically disproportionate to that of mature cattle. The 2 calves used were also beef calves, and clinically important anatomic differences may exist between beef and dairy breeds, which may preclude extrapolation of our results to cattle of different production classes. Additionally, we found great variability in the resultant angles obtained from our 2 cadaver calves. Thus, more animals need to be studied to provide surgical guidance regarding the ideal limb angle during prosthetic placement.

Although the results of this study provide a foundation for reconstructing the bovine coxofemoral joint, additional research is needed to construct the ideal prosthetic and provide adequate instruction for placement. Although previous reports describe a successful outcome of up to 70% with the use of a toggle pin implant, long-term follow-up was not provided and coxofemoral luxation unresponsive to closed reduction carries a poor long-term prognosis.

Future aims of this study are to provide more information on the normal and traumatic forces acting on the coxofemoral joint of cattle and the stability provided by the joint capsule and surrounding musculature. Additionally, this study aims to provide more precise guidelines for placement of a toggle pin implant and in vivo data of its use. The authors recognize the lack of data reported on placing the prosthesis as it would be performed in surgery, through the femur coursing the coxofemoral joint and toggling medially to the acetabulum, as well as the functionality of its placement. It is the authors’ goal to provide this information in future reports.

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References


**Supplementary Materials**

Supplementary materials are posted online at the journal website: avmajournals.avma.org.