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Original Study

Ex Vivo Pullout Strength of Locking and Cortical Screws in the Femur and Tibiotarsus of the Pekin Duck (*Anas platyrhynchos domesticus*)

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Abstract: The development of smaller orthopedic plates and screws has facilitated their use in avian fracture repair. Avian bone differs from mammalian bone in its biomechanical properties due to adaptations for flight, necessitating avian-specific orthopedic biomechanical studies. Screw pullout strength has not been studied in avian bone. The aims of this study were to 1) compare the axial pullout strength of cortical and locking screw designs in the tibiotarsus and femur of the Pekin duck (*Anas platyrhynchos domesticus*) and 2) investigate the effects of sex and screw location in bone on screw pullout strength. Locking and cortical screws were inserted in 5 locations: the distal metaphysis, distal diaphysis, middiaphysis, proximal diaphysis, and proximal metaphysis of femora ($n = 28$) and tibiotarsi ($n = 40$) from 20 Pekin ducks. Screws were tested to failure in axial pullout and maximum force recorded. Data were analyzed by a linear mixed-effects model. There were no significant differences in screw pullout strength between locking and cortical screws or between sexes. On average, maximum force was highest at the middiaphysis in the femur and at the distal diaphysis of the tibiotarsus. These results suggest that when using 2.0-mm and 1.5-mm screws in avian femoral and tibiotarsal bones, respectively, screw positioning in denser diaphyseal regions may be more critical to screw pullout strength than the choice between cortical and locking screw designs.

Key words: orthopedic, holding power, bone, screw pullout strength, avian, Pekin duck, *Anas platyrhynchos domesticus*

INTRODUCTION

The avian skeleton has adapted to flight by increasing bone strength while maintaining a lightweight frame.[1] This is achieved with thin, dense cortices and pneumatization of bones. Traditionally, external fixation has been the preferred repair technique for avian fractures; however, with the development of smaller implants, bone plating is becoming more common in avian clinical practice.

Screw or pin loosening is a major cause of implant failure. Pullout strength of screws, defined by the amount of force required to remove a screw from bone,[2] is influenced by bone properties, insertion technique, and pin or screw designs.[3–6] Numerous biomechanical studies have focused on optimizing implant placement and reducing implant failure in mammals; however, few such studies exist for avian species.[7–10]

To our knowledge, screw pullout strength has not been studied in avian bone. A study evaluating different miniplate systems in pigeons reported screw loosening with implants using higher–thread-pitch screws, and no screw loosening with the use of lower–thread-pitch screws.[11] These findings were consistent with the findings on thread pitch in pins in avian bone.[7] The effects of screw design, including thread pitch, on the holding power of screws in avian bone should, therefore, be investigated further.

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Table 1. Dimensions of cortical and locking screws[13] used in 4 allocated treatment groups: (A) 2.0 mm cortical screws, (B) 2.0 mm locking screws, (C) 1.5 mm cortical screws, and (D) 1.5 mm locking screws for axial screw pullout strength testing in Pekin ducks (*Anas platyrhynchos domesticus*).

	A	B	C	D
Size, mm	2.0	2.0	1.5	1.5
Design	Cortical	Locking	Cortical	Locking
Thread pitch, mm	0.6	0.75	0.5	0.6
Thread depth, mm	0.8	0.75	0.6	0.4
Core diameter, mm	1.4	1.5	1.1	1.0
StarDrive recess[a]	T6	T6	T4	T4

[a] Stardrive recess refers to a six-lobed, star-shaped (Torx-type) screw head. T4 and T6 denote the size of the corresponding driver required for each screw type.

The purpose of this study was to 1) compare the axial pullout strength of cortical and locking screw designs in the tibiotarsus and femur of the Pekin duck (*Anas platyrhynchos domesticus*) and 2) investigate the effects of sex and screw location in bone on screw pullout strength. We hypothesized that the cortical screw design would have greater pullout strength due to the finer thread pitch and greater thread depth compared with locking screw designs.

MATERIALS AND METHODS

Twenty pairs of femora and tibiotarsi were harvested from skeletally mature market-bought Pekin duck carcasses weighing between 2.2 and 2.4 kg. Specimens were obtained from a commercial duck meat producer following processing for human consumption.

A 1-cm^3 sample of pectoral muscle was harvested from each duck and submitted to a commercial laboratory for DNA sexing. The DNA sexing results were blinded during treatment allocation and while biomechanical testing was completed.

Soft tissue was removed by sharp dissection. Femora and tibiotarsi were wrapped in saline-soaked gauze and stored for approximately 2 months at −20°C.[12] Bones were thawed to room temperature prior to testing.[10] Femora and tibiotarsi were radiographed in craniocaudal and mediolateral projections (Porta 100HF, Radincon X-ray, Dee Why, NSW, Australia; CXDI-50G, Canon, Mississauga, ON, Canada) set at 56 kV and 1.0 mAs. Endosteal width at the isthmus of each bone was measured with the WEASIS Medical DICOM Viewer (https://weasis.org/en/index.html) and screw size was calculated based on 30%–40% of the endosteal width on the craniocaudal projection. Based on these measurements, 20 of the tibiotarsus pairs were allocated a 1.5-mm screw size and 14 pairs of femora were allocated a 2.0-mm screw size. The remaining 6 pairs of femora were excluded from the study due to being smaller in size.

Twenty-eight femora from 14 ducks were allocated into 2 equal treatment groups at random: group A, 2.0-mm cortical screws, and group B, 2.0-mm locking screws. Forty tibiotarsi from 20 ducks were allocated into 2 equal treatment groups: group C, 1.5-mm cortical screws, and group D, 1.5-mm locking screws. All screws used in the study were commercially available stainless steel, self-tapping screws with a StarDrive recess and were manufactured by the same company (Veterinary Orthopedics Implants, Movora, St Augustine, FL, USA).[13] The dimensions of each screw type are detailed in Table 1. Cortical screws had finer thread pitch and greater thread depth compared with locking screws (Table 1).

Five equidistant screw locations were allocated to each bone: (1) distal metaphysis, (2) distal diaphysis, (3) middiaphysis, (4) proximal diaphysis, and (5) proximal metaphysis (Fig 1). Bones were positioned in a custom jig to standardize positioning, and each screw location was predrilled perpendicular to the bone by the same surgeon in a mediolateral orientation in the tibiotarsus and a lateromedial orientation in the femur, as would be clinically applicable. A 1.1-mm drill bit was used for both 1.5-mm screw types and 1.5-mm drill bit for both 2.0-mm screw types. Respective screws were hand inserted with a standard driver in the predrilled hole in the same orientation, with a minimum of 2 threads protruding through the transcortex. All screws were inserted by 1 surgeon for consistency and each screw was new and used only once during the study.

Biomechanical testing

Specimens were tested with a calibrated servohydraulic testing machine (MTS Mini Bionix 858, MTS Systems, Eden Prairie, MN, USA). The bones were kept moist in saline and testing was done at ambient air temperature. Bones were positioned perpendicularly, with

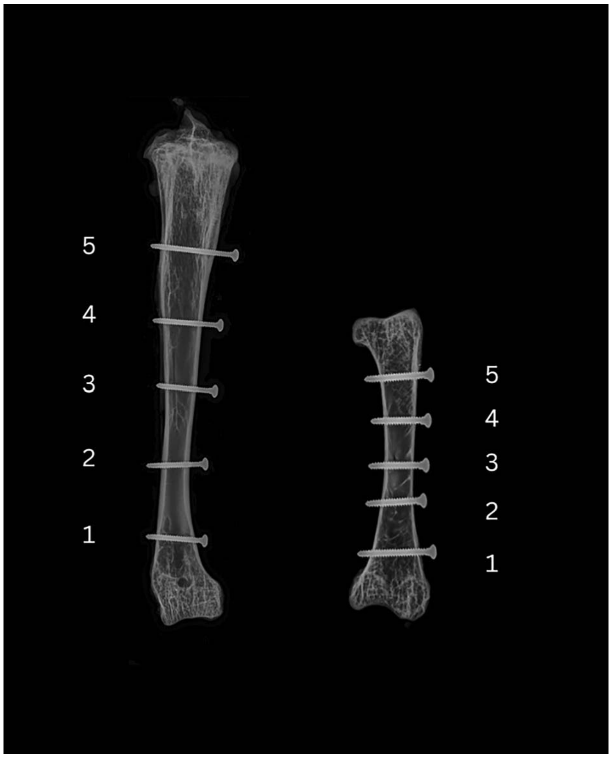

Figure 1. Radiographs of a tibiotarsus with mediolateral insertion of 1.5-mm cortical screws (left) and femur with lateromedial insertion of 2.0-mm cortical screws (right) demonstrating the 5 screw placement locations (1, distal metaphysis; 2, distal diaphysis; 3, middiaphysis; 4, proximal diaphysis; 5, proximal metaphysis) in a Pekin duck (*Anas platyrhynchos domesticus*).

screw heads engaged in a custom jig (Fig 2). Stainless steel carabiners were used to secure the bone in the correct position and allow for axial pullout. Screws were extracted axially with an applied extraction force of 10 mm/min.[10] Maximum force (MF) was recorded for each insertion point in Newtons (N).

Statistical analysis

The data were analyzed by linear mixed-effects models.[14] Separate models were fitted to the tibiotarsus and femur data. Fixed effects were used to estimate differences in MF due to location, screw type, and sex, and all 2- and 3-way interaction effects between these variables were considered. To account for multiple measurements being taken on each duck and on each bone, random effects and the duck and bone levels were considered. The models were fitted using the R package lme4.[15] A $P < 0.05$ was considered statistically significant. The data and code are available at the following URL: https://github.com/b-steve/duck-bones/.

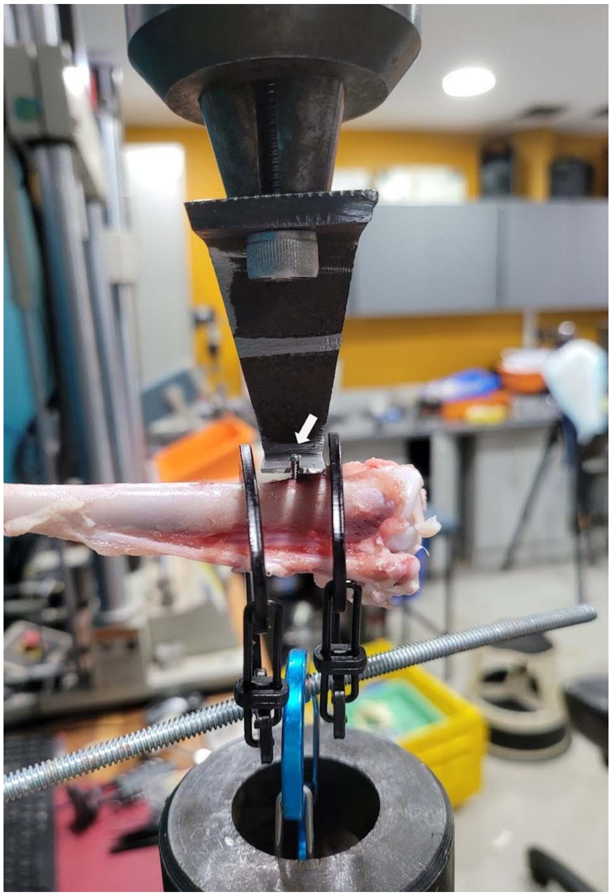

Figure 2. Tibiotarsus of a Pekin duck (*Anas platyrhynchos domesticus*) with 1.5-mm locking screw (white arrow), inserted mediolaterally, at the proximal metaphysis (location 5). The screw head is engaged in a custom-made testing jig prior to axial screw pullout testing with a servohydraulic testing machine.

RESULTS

Of the 20 duck carcasses used in this study, 11 were male and 9 were female. The DNA sexing results for each treatment group, allocated at random, are listed in Table 2. One tibiotarsus and 1 measurement of MF at location 3 in 1 femur were excluded from the study due to technical error.

Table 2. Distribution of sex in treatment groups (locking or cortical screws) for the femora and tibiotarsi of Pekin ducks (*Anas platyrhynchos domesticus*).

	Femur		Tibiotarsus	
Screw design	Male	Female	Male	Female
Cortical	5	2	6	4
Locking	5	2	5	5

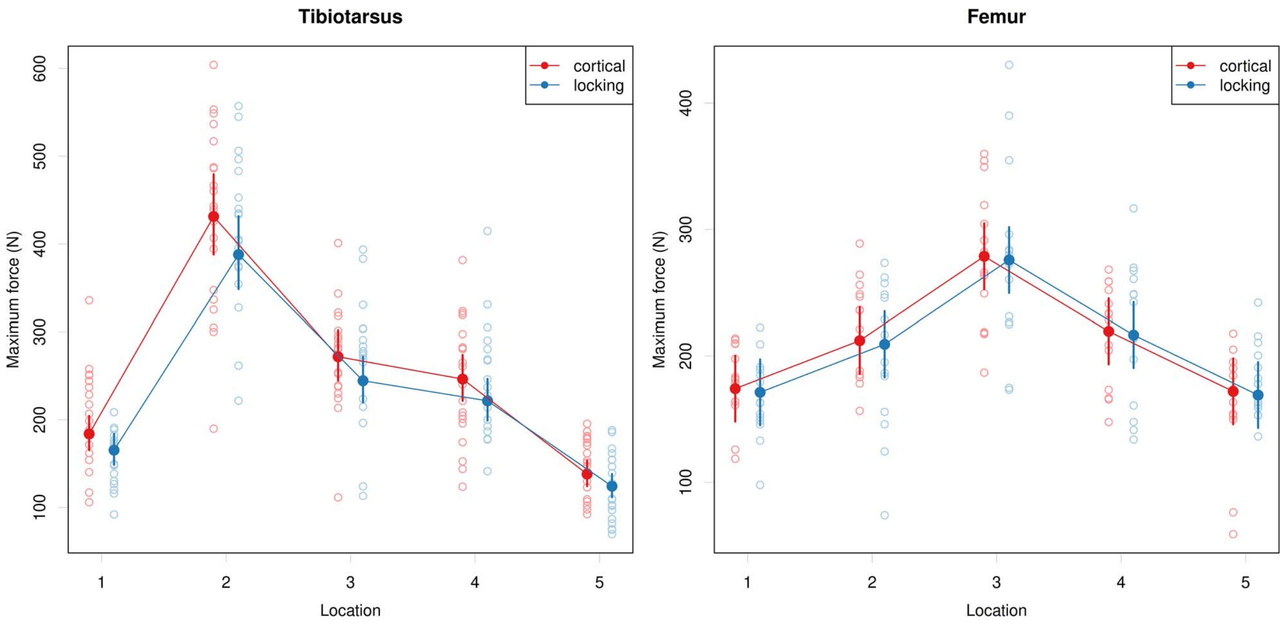

Figure 3. Scatterplot of maximum force (MF), in Newtons (N), and estimated from the linear mixed-effects models, average MF (95% confidence interval [CI]) for cortical (red) and locking (blue) screws at different locations in the tibiotarsus and femur. A log transformation was used for the tibiotarsus models; therefore, these estimates and CIs were computed for the log of MF prior to being back transformed for this plot. Estimated average MF is for the average duck based on linear mixed-effects models. Locations: (1) distal metaphysis, (2) distal diaphysis, (3) middiaphysis, (4) proximal diaphysis, (5) proximal metaphysis.

Initial models were considered that included up to 3-way interactions between the fixed effects (location, screw type, and sex), and both duck- and bone-level random effects. Model checking revealed minor heteroscedasticity for the tibiotarsus data, which was eliminated after applying a log transformation to MF. The same issue was not present for the femur data, so a transformation was not applied. Otherwise, checking assumptions for all models that were considered did not reveal any issues with linearity assumptions, and no outliers were present. Residuals were slightly skewed for all models, but linear mixed-effects models are robust to errors that depart slightly from normality.

Initial models for both the tibiotarsus and femur data did not reveal evidence for the presence of any interaction effects, nor for differences in MF between males and females ($P = 0.27$ for tibiotarsus, $P = 0.63$ for femur), so interaction and sex effects were removed from subsequent models. Although differences between screw types were not statistically significant, they were retained in the final models because screw type is the primary variable of interest in this study.

The variance of the bone-level random effects was estimated to be 0 for both the tibiotarsus and femur data, consistent with both bones of the same type within each individual duck being identical in terms of average MF measurements. The bone effects were therefore removed from the models.

The final models therefore included fixed effects of location and screw type and random effects for individual ducks. For both bone types, there was strong evidence of differences in MF due to locations ($P < 0.001$ for both tibiotarsus and femur), but differences between screw types were not statistically significant ($P = 0.07$ for tibiotarsus, $P = 0.86$ for femur). There was statistically significant variation between ducks, confirming the importance of including duck-level random effects ($P = 0.02$ for tibiotarsus, $P < 0.001$ for femur).

Estimates and confidence intervals for the average MF under different combinations of location and screw type were calculated from the model (Fig 3). Estimated average force was highest at the distal diaphysis for the tibiotarsus and at the middiaphysis for the femur, and lowest at the distal and proximal metaphyses for both bone types.

A log transformation was used for the tibiotarsus models, and so interpretations of effects are multiplicative, corresponding to percentage differences between screw types in MF. Log transformation was not required for the femur models and so interpretations are in terms of differences in force (N) between screw types. Under the models, using a cortical rather than locking screw type increased the average MF by an estimated 2.9 N for the femur. For the tibiotarsus, using a cortical rather than locking screw type increased the MF by 11%. However, these differences were not statistically significant. Under 95% confidence intervals for these estimates, the difference for the femur could plausibly be as large as 34.3 N in favor of cortical screws or 28.5 N in favor of locking screws. For the tibiotarsus, the difference between screw types could plausibly be as large as 24.0% in favor of cortical screws or 0.3% in favor of locking screws.

DISCUSSION

The current study found no statistically significant difference in screw pullout strength between cortical and locking screw designs, but significant differences were detected across different locations of both the tibiotarsus and femur.

The thread depth in the current study varied between cortical and locking screw designs, with cortical screws having a greater thread depth (Table 1). Greater thread depth has been shown to enhance screw pullout strength in cancellous bone by increasing the surface area engaged with the bone,[16,17] but does not play a significant role in small bone screws used in thin cortical bone.[18] Therefore, it was expected that screws with greater thread depth would outperform screws with lower thread depth in the metaphyseal sites. However, our findings did not support this. Comparison of cancellous screws, which possess greater thread depth, may be warranted; however, those were not commercially available in 1.5-mm size at the time of this study. Analysis of cortical thickness and screw thread–cortex engagement, as well as macrostructure and density of the bone at each site, may provide further understanding of these results. Further research with controlled variables is required to determine the significance of thread depth in avian bone.

Regional differences in implant performance were observed in a study on the pullout strength of threaded pins in the common buzzard (*Buteo buteo*); the difference was attributed to thread pitch.[7] In that study, thread pitch of partially threaded 1.5-mm negative profile fixation pins was approximately twice as fine compared with screw thread pitch in the current study.[7] The differences between cortical and locking screw thread pitch in the 1.5-mm and 2.0-mm screws used in the current study were 20% and 25%, respectively. Comparatively, the difference in thread pitch between threaded pins in the previous study was 32%.[7] It is possible that the difference between thread pitch in the current study was too small to detect a significant difference.

Similar to the current study, López Garcia et al[10] found no significant difference of pin pullout strength at specific bone location when comparing different pin thread pitch; however, they did report a difference in thread pitch performance between pneumatic and medullary bones. The comparison of pneumatic and medullary bone could not be made in the current study due to the absence of pneumaticity in femurs of the domestic duck.[19,20] Additionally, meaningful statistical comparison between the femur and tibiotarsus could not be performed due to the use of different screw sizes tailored to each bone's dimensions, as well as the substantial anatomical and functional differences between the bones. These differences precluded direct comparison of screw insertion sites in terms of cortical thickness, medullary cavity size, and local bone density, limiting the validity and clinical relevance of such an analysis.

Screw size in this study was selected based on accepted recommendations for small animal surgery.[12] Studies have shown variation between species in acceptable screw size selection and effect on bone strength.[12,21] One study found more than 50% loss of bone strength in rabbit bones with screw hole diameters >15%,[21] compared with the recommended 33% in cats,[12] which was attributed to the brittle nature of rabbit bones. Optimal screw size is likely dependent on bone composition and strength; however, to date, there is no published literature on the optimal screw size for avian bone, and further research is required.

Increased bone density is associated with greater screw pullout strength.[22] Bone density, bone mineral content, and bone strength have been shown to differ between male and female birds depending on age and development.[23–25] Female ducks in 1 study showed lower bone mineral content compared with males, and male ducks had increased mechanical strength.[25] Bone density has also been demonstrated to vary across bone locations.[23,24] Age, sex, level of activity, diet, and environment are all factors that influence bone density, and therefore may indirectly affect screw pullout strength in avian bone.[23,26] This study aimed to eliminate some of this variation by sourcing duck carcasses of the same age, size, and rearing environment.

This study found no significant difference in performance between screw designs based on sex. One consideration was the small number of females compared with males in the femur treatment groups

(Table 2), which resulted in the hypothesis test for the presence of a sex effect having low power. Treatment groups were allocated blindly, and DNA sexing results were available only after biomechanical testing was complete. Of the 20 duck carcasses used in this study, only 14 femora were used due to size selection to accommodate 2-mm screws. Six femora were excluded because they were too small. This correlated with a lower number of females ($n = 4$) compared with males ($n = 10$) for femora tested, whereas there was more equal distribution between males ($n = 11$) and females ($n = 9$) for tibiotarsi. Despite blind allocation, there was a relatively equal distribution of numbers of females in each treatment group (locking and cortical screws) and a relatively equal number of males (Table 2). Future studies could improve consistency by pairing left and right femurs from the same individual, therefore assigning 1 limb to each screw type to further control for interindividual anatomical variation and provide more direct comparisons between implant types.

To ensure rigorous analysis and avoid common statistical pitfalls,[27] a statistician was involved in the statistical analysis of this study. Random effects are required when multiple measurements are taken on individual subjects to avoid pseudoreplication.[28] In this study, up to 5 measurements were taken on each individual bone, and up to 10 measurements were taken on each individual duck for each bone type (tibiotarsus or femur). Variation between ducks was minimized by sourcing duck carcasses of the same cohort from a single commercial facility and therefore exposed to similar conditions. However, the MF was higher for some ducks than others due to natural variation. Similarly, natural variation may exist between 2 bones of the same type within a duck, such that MF measurements on 1 tibiotarsus may be lower or higher than measurements on the other. Random effects for bones and ducks were therefore considered in this analysis, and traditional repeated analysis of variance was deemed inappropriate. By addressing these concerns, this study adheres to best practices that ensure reliable and valid results, reinforcing the importance of robust statistical methods in avian research.[27]

Understanding screw performance in bone can inform clinical decision-making to reduce fixation failure and improve patient outcomes. This study did not find a significant difference between locking and cortical screw designs, and therefore surgeon preference can dictate this choice. However, there are significant regional differences between screw pullout strength in avian bone, and the location of screw placement is more likely to be influential to clinical outcomes, with diaphyseal sites yielding greater pullout strength than metaphyseal sites for both femora and tibiotarsi. Surgeons should prioritize screw location over screw design when considering implant fixation in avian long bones. Whereas this study focused on isolated screw performance, it is important to acknowledge that plate-screw constructs, particularly locking plate systems, introduce additional biomechanical considerations such as load distribution through the fixed-angle plate-screw interface, reducing reliance on screw-bone purchase. Future studies are needed to assess the biomechanical performance of complete plate-screw systems under clinically relevant loading conditions in avian bone. Nevertheless, the current study provides essential baseline data on screw-bone interactions, which is a necessary foundation for the design and interpretation of more complex construct-level investigations.

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