Tibial tuberosity avulsion fractures (TTAFs) are relatively uncommon traumatic injuries in the young canine. TTAFs usually occur around 4 to 10 months of age, but are reported between 2 and 22 months of age, and American Staffordshire Bull Terriers and large breeds may be predisposed. Tibial tuberosity (TT) apophyseal closure is typical by 8 to 11 months, but can take up to 22 months in some large breeds, which may increase their risk for TTAFs. Avulsion often occurs during jumping activities, likely as a consequence of increased distraction forces applied through the patellar tendon during contraction of the quadriceps femoris muscle while the stifle is flexed and the foot is grounded. This is consistent with a findings of a previous report that indicate highly muscular breeds are overrepresented because increased muscle mass may increase distraction forces. Conventional wisdom is to repair the fracture if, subjectively, the tuberosity is more than minimally displaced on radiography or if it is mobile on physical examination. Conversely, if the TT is already nonmobile on physical examination and subjectively minimally displaced on radiography, conservative management may be more appropriate. The most commonly performed surgical fixation is with 2 Kirschner wires (K-wires) with or without a tension band. Historical recommendations have been to remove the implants early to avoid premature closure of the apophysis and the potential distal translation of the tuberosity, especially in patients with sub-

**OBJECTIVE**

To evaluate outcomes of tibial tuberosity avulsion fractures (TTAF) in dogs with implants left in situ past skeletal maturity and to compare clinical outcomes with published outcomes in dogs whose implants were removed 4 to 6 weeks postoperatively.

**ANIMALS**

47 client-owned dogs.

**PROCEDURES**

In this retrospective study, 47 dogs had surgery to correct a TTAF before 10 months of age and had the implants left in situ past skeletal maturity. Of these, 42 were followed for a median of 36 months postoperatively. Short- and long-term complications were recorded and compared with historically published data in which the implants were removed within 6 weeks of surgery.

**RESULTS**

14% (6/42) of our population experienced minor long-term complications (stiffness and lameness), 6% (3/47) experienced major short-term complications (repair failure), and 14% (6/24) experienced major long-term complications (implant removal). There was no difference in long-term outcomes when compared with results of historical reports in which implants were removed 4 to 6 weeks postoperatively. Client satisfaction was high, with 93% (38/41) grading outcomes as excellent and 95% (39/41) stating they would have surgery performed again in retrospect.

**CLINICAL RELEVANCE**

Immature dogs with surgically repaired TTAFs have favorable long-term outcomes when the implants were left in situ past skeletal maturity. Dogs with TTAF repairs may not need implant removal unless it becomes clinically necessary. Avoiding a second procedure will decrease patient morbidity, recovery time, and cost.
Substantial growth potential. The ideal time for removal has not been studied, but most reports suggest 4 to 6 weeks postoperatively. Based on earlier studies, despite early implant removal, 42% (3/7) to 90% (36/40) of patients may already have premature apophyseal closure by 4 to 6 weeks, although they still typically achieve good clinical outcomes. In a study by Gower et al, the largest published study with long-term follow-up, 32 of 40 dogs had implants removed 4 to 6 weeks postoperatively and 36 of 40 patients already had bony bridging of the apophysis.

On recheck evaluation, a mean of 14 months after surgery, 24 of 31 dogs were clinically sound, 4 of 31 had minor stiffness, and 3 of 31 patients had a mild lameness. Surgery for implant removal is often minimally invasive, but may require sedation or occasionally full anesthesia. This second procedure may require additional patient recovery and healing times as well as adding to owner time commitments and costs. Many surgeons, therefore, elect not to remove the implants and have anecdotally not observed any worsening of clinical outcomes, although no studies have yet been performed that focus on the short- and long-term outcomes when implants are left in situ past skeletal maturity.

The purpose of this paper is to evaluate the short and long-term outcomes of dogs after TTAF repairs when implants are left in situ past skeletal maturity and to compare these results with past studies where implants were removed 4 to 6 weeks postoperatively. We hypothesize that dogs without implant removal prior to skeletal maturity will have positive short-term (< 3 months) and long-term (> 1 year) clinical outcomes, comparable to findings from past studies with early implant removal.

**Materials and Methods**

Records from the Metropolitan Veterinary Hospital in Akron, Ohio, and the Las Vegas Veterinary Specialty Center were reviewed. All dogs surgically treated for a TTAF with 2 K-wires, with or without a tension band, were identified. Dogs were excluded if they were older than 10 months, if implants were removed before 12 months of age, had a different repair method, or if medical records were incomplete. The Metropolitan Veterinary Hospital provided 16 dogs between January 2015 and July 2020, and 41 dogs were provided by the Las Vegas Veterinary Specialty Center between January 2008 and July 2020. Ten dogs were removed based on the exclusion criteria.

Signalment for each dog was recorded. Breeds were categorized as small or large based on a breed standard weight of < or > 20 kg, respectively. The date of surgical repair and all rechecks were documented. Short-term was defined as < 3 months and long-term as > 1 year. To evaluate the short-term outcomes, the clinical records were searched for any in-clinic recheck by a surgeon or surgical resident within 3 months of surgery. Based on these in-clinic recheck notes, short-term clinical outcomes were recorded, including any complications as previously described. Dogs were excluded from short-term evaluation if there was no in-clinic recheck. The initial study design was intended to have an in-clinic evaluation of patients by a surgeon or surgical resident for long-term clinical outcomes; however, the COVID-19 pandemic prevented this from happening. The decision was then made to perform an owner telephone questionnaire. Owner evaluation was conducted by a modified telephone questionnaire during October and November 2020 to evaluate the long-term clinical outcomes and owner satisfaction. A 4-point lameness guide was described to the owner (Supplementary Table S1).

**Results**

During the study period 57 TTAF repairs were performed, 47 of which fit the inclusion criteria. One owner declined to participate in the questionnaire, and 5 could not be reached. One of the unreachable owners had previous long-term follow-ups at the clinic. The clinical data from this patient and from the 41 owners that completed the questionnaire were used for long-term evaluation. The median follow-up time was 36 months (range, 12 to 149 months) after surgery. Outcomes and comparisons to historical data were compiled (Table 1).
Table 1—Summary population demographics and outcomes with associated 95% CIs for 47 client-owned dogs that had tibial tuberosity avulsion fractures surgically corrected before 10 months of age and had the implants left in situ past skeletal maturity, compared with findings from previously published data. All historical data is of tibial tuberosity avulsion fractures except where indicated.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Present study</th>
<th>Previous studies (reference number)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Result</td>
<td>[1] [2] [3] [22] [16] [17]</td>
</tr>
<tr>
<td>Small breeds</td>
<td>34% (16/47)</td>
<td>20.8%–49.3% 6.8% (4/59)† 4.7†</td>
</tr>
<tr>
<td>Mean age (mo)</td>
<td>5.7</td>
<td>5.3–6.2 4.9† 7.3‡</td>
</tr>
<tr>
<td>Median age (mo)</td>
<td>5</td>
<td>— 5* — 12‡</td>
</tr>
<tr>
<td>Male sex</td>
<td>65.9% (31/47)</td>
<td>50.7%–79.1% 55.9% (33/59)* 53.8% (35/65)</td>
</tr>
<tr>
<td>Left-sided TTAFs</td>
<td>61.7% (29/47)</td>
<td>46.4%–75.5% 55% (3/55) 30% (3/10)</td>
</tr>
<tr>
<td>Short-term lameness</td>
<td>at 1–8 w</td>
<td>at 4–6 wk† at 3–6 wk†</td>
</tr>
<tr>
<td>Long-term lameness</td>
<td>14.3% (6/42)</td>
<td>5.4%–28.5% 22.6% (7/31)*</td>
</tr>
<tr>
<td>Short-term MC</td>
<td>6.4% (3/47)</td>
<td>1.3%–17.5% 14.3% (1/7)* 18.2% (2/11)‡</td>
</tr>
<tr>
<td>Long-term MC</td>
<td>14.3% (6/42)</td>
<td>5.4%–28.5% — — MPL TTT — — MPL TTT</td>
</tr>
</tbody>
</table>

Data reported as percentages and proportions unless otherwise noted.
Bracketed numbers in the column headings are article citations with reported outcomes similar to the current study*, less than the current study†, or more than the current study‡ based on the calculated CIs.
— = Not applicable. MC = Major complications. MPL = Medial patellar luxation. TTT = Tibial tuberosity transposition.

The mean age at diagnosis was 5.7 months (range, 3 to 8 months; 95% CI, 5.3 to 6.2 months; median, 5 months). Thirty-one dogs were male (20 sexually intact and 11 castrated) and 16 were female (14 sexually intact and 2 spayed). Large breeds accounted for 31 of the 47 patients, whereas 6 were small breeds. The most common breeds or types included the French Bulldog (9), pit bull–type breeds (6), Old English Bulldogs (4), and Maltese-Toy Poodle crosses (3). TTAFs were left-sided in 29 patients and right-sided in 18. A tension band and 2 K-wires were used in 35 of 47 repairs, and 2 K-wires were used alone in the remaining 12 repairs. By study design, no patient had implant removal before 12 months of age.

Three patients did not return for an in-clinic recheck within 3 months of the surgery, leaving 44 patients in which to evaluate short-term outcomes. Rechecks occurred a median of 4 weeks postoperatively (range, 1 to 12 weeks). Thirty-six of 44 (82%) patients were clinically normal, 7 had a grade 1 lameness, and 1 had a grade 2 lameness. Of the lame dogs, 1 had no long-term follow-up and 2 continued to have occasional stiffness long-term. The last 5 had normal ambulation by week 12. One of the 5 did become lame on the ipsilateral limb 2 years later and was diagnosed with pin migration. After implant removal, the dog recovered fully with no lameness nor stiffness.

Questionnaire results
All 47 patients were non–weight-bearing to toe touching at diagnosis. At follow-up, 36 of 42 (85.7%) patients were clinically normal, 5 had occasional stiffness when standing up, and the remaining patient had a consistent waxing and waning grade 1 to 2 lameness. The time to reach their peak ambulatory status after surgery was a median of 8 weeks (range, 2 to 16 weeks).

Major short-term complications were noted in 3 of the 47 (6%; 95% CI, 1.3% to 17.5%) patients. The initial repair failed in these patients within 4 weeks and was revised. These owners responded to the questionnaire 6, 6.5, and 7 years later. One needed implant removal at 13 months of age due to implant irritation and recovered with no residual lameness. Another had occasional stiffness long-term, and the last recovered with no residual lameness.

Major, long-term complications necessitating implant removal were noted in 6 of 42 (14%; 95% CI, 5.4% to 28.5%) patients. Four had pin migration at 12, 13, 16, and 28 months of age. One had an implant-associated infection 8 years later. The last patient had pin irritation at 13 months of age. All 6 patients had the implants removed and recovered with no residual lameness.

Minor, long-term complications were noted in 6 of 42 patients (14%; 95% CI, 5.4% to 28.5%). Five owners reported mild stiffness on the surgical leg when rising that the patients quickly warmed out of and had minimal effect on their daily life. The sixth owner noted a consistent, mild to moderate lameness that waxed and waned with activity. Further evaluation of this patient was not possible, so it cannot be confirmed if the lameness was due to the TTAF surgery or if there was an alternate reason for the lameness such as a cruciate tear or medial patellar luxation. Regardless, our minor, long-term complication rate is similar, but slightly lower, than reported by Gower et al (Table 1).

When owners were asked how effective the surgery was, based on a scaled system, 38 of 41 (95%) quantified it as 4/4 effective. The remaining 3 rated it as 3/4 effective. Similarly, when asked if, in retrospect, they would have pursued the surgery or considered other options such as splinting and crate rest, 39 of 41 (95%) gave a firm “yes,” 1 said “probably” depending on the situation, and the last individual stated that they would have explored other options.

Discussion
Our data suggests that early removal of implants after repair of TTAFs in immature dogs may be un-
necessary. We found no meaningful differences in long-term clinical outcomes between our patient population with implants left in situ past skeletal maturity and the population reported by Gower et al. in 2008, where implants were removed 4 to 6 weeks postoperatively (Table 1). This supports our hypothesis that the long-term clinical outcomes in our patient population is similar to those of past studies with early implant removal. There was, however, a difference in the reported short-term outcomes, with more short-term lameness noted in our study versus Gower et al. As such, our hypothesis that the short-term outcomes would be similar to past studies was not affirmed.

The reason behind early implant removal after TTAF repairs has historically been to avoid premature closure of the apophysis. The concern with early closure is the apparent distal migration of the TT as the proximal tibial physis continues to grow. Whether early implant removal affects the incidence of apparent TT distalization has not been investigated; however, 42% (3/7) to 90% (36/40) of dogs show bony bridging of the apophysis by 4 to 6 weeks after surgery. As far as the authors are aware there are no reports of this distalization being linked to clinically important outcomes and 2 studies specifically note no clinically important sequelae. While not reported, in theory, the distalization may place increased tension through the patellar ligament and may cause patella baja. Increased patellar ligament tension has been theorized to predispose to repeat TT or patellar fractures. While failure of the TTAF repair is well described, patella baja and patellar fractures are not a reported sequela to TTAF repairs. In humans, patella baja has been associated with reduced knee range of motion and an increase in the patellofemoral contact pressure, leading to cartilage wear and arthrosis. In canines, however, even moderate patella baja is well tolerated without clinically important sequelae. The only exception in veterinary literature is an association between patella baja and laterally luxating patellas, but a causative relationship was not established. Regardless, the current population did not suffer from diminished long-term outcomes secondary to leaving the implants in situ past skeletal maturity.

At the last surgical recheck, 18% (8/44; 95% CI, 6.5% to 29.8%) of our patients were lame, while Gower et al. reported 6% (3/56) lame, which is less than the lower bound of our CI (Table 1). A likely reason for this discordant finding is the difference in follow-up time. The Gower et al. population was evaluated 3 to 6 weeks postoperatively (median, 4 weeks). Our population was also rechecked at a median of 4 weeks, but the range was greater, with several being rechecked at 1 to 2 weeks, thus finding more lameness is unsurprising. A theoretical model was created to test our assumption that the difference in outcomes was due in part to the variance in follow-up times. The questionnaires were searched for all patients that were rechecked at 1 to 2 weeks to see if they were sound by 3 to 4 weeks postoperatively. Half of them were sound, leaving 4 of the 44 (9%) patients lame at 3 to 4 weeks; the 95% CI for this proportion was 0.4% to 17.8%, which incorporated the 6% (3/35) reported by Gower et al. This model highlighted the importance of similar follow-up times to accurately compare outcomes. As such, our failure to find similar short-term outcomes may have been due to our dissimilar follow-up times.

Minor long-term complications were noted in 6 of 42 patients (14%; 95% CI, 5.4% to 28.5%), similar to recent reports. An abstract by Moyer et al. followed 33 patients after TTAF repair and reported a minor long-term complication rate of 25%. Gower et al. followed 31 patients a mean of 14 months after surgery and reported a minor long-term complication rate of 23% (7/31), with 5 patients displaying mild stiffness and 2 with intermittent lameness. These results fit within this study’s CI (Table 1).

Our major, short-term complication rate was 6% (3/47; 95% CI, 1.3% to 17.5%). Gower et al. did not report any major short-term complications, although they did report what they classified as 12 minor short-term complications at or prior to early implant removal: 4 broken tension wires, 2 misplaced K-wires, 3 seromas, and 5 loose K-wires. It is arguable that the broken wires, misplaced K-wires, and loose K-wires could have been classified as short-term major complications since, had their early removal not already been planned, the implants would have likely needed to be removed at some point with a second procedure. Other studies, with low case numbers report 14% (1/7) and 18% (2/11) short-term major complications, which are similar to that found in our data. There are no other TTAF studies with adequate case numbers and long-term follow-up, but 1 study of 100 mature dogs with tibial tuberosity transpositions (TTT) had a similar short-term major complication rate of 18% (18/100; Table 1). The major, long-term complication rate, necessitating implant removal, was 14% (6/42; 95% CI, 5.4% to 28.5%). Both our population and that from Gower et al. had no surgeries on the ipsilateral limb during the follow-up period aside from implant removal. Because the majority of implants were removed by 4 to 6 weeks in the previous study, the major long-term complications cannot be directly compared. Our major long-term complication rate is similar to those in a recent abstract reporting a total major complication rate of 25% after TTAF repairs. There are no other adequately large studies with long-term follow-up for TTAF repairs, but our rate is similar to those in mature patients that received a TTT as part of a medial patellar luxation corrective surgery; 7% (7/100) to 17.5% (24/137) in recent studies (Table 1).

Pin migration is a well-known complication whenever a nonthreaded pin is placed, and pin irritation or seroma is often noted when minimal soft tissue is overlying any pin. Stanke et al. followed 137 patients a median of 104 days after a TTT as part of a medial patellar luxation corrective surgery. Twenty-five of 137 (18.2%) patients developed a pin irritation or seroma. Several weeks postoperatively, 25% (16/65) patients had radiographic evidence of pin migration. Those complication rates are higher.
than our population, which had an incidence of 2% (1/42) irritation or seroma and 10% (4/42) for pin migration. Differences in data collection may partially explain this discrepancy. In our population, K-wire migration or irritation was only noted if it caused a clinical problem and thus may be underreported. Differences in K-wire placement may also play a role. Studies have shown that to avoid migration, pins and K-wires should be placed to engage but not protrude through the trans cortex.17-19 The angle of placement is also important in TT repair success, with higher failure rates when K-wires are directed caudodistally.20 It is recommended to place the K-wires perpendicular or slightly caudoproximal to the tibial axis or to use a tension band.10,20 Using threaded pins or bending pin ends may help, and bent pin ends may also decrease the risk for seroma formation.8,17,21

Similar to previous studies, all TTAFs occurred in immature dogs < 10 months of age.1,2,4,7,10,22 When comparing our patient population to that in the study by Gower et al.,2 the primary difference in patient signalment was our higher proportion of small breeds (Table 1). Large breeds were still the majority of our cases, but 34% (16/47; 95% CI, 20.8% to 49.3%) were small breeds, 9 of which were French Bulldogs. Whether this demographic difference has any effect on the clinical outcomes is unknown. The mean age of our population was older than that of Gower et al.2: 5.7 (95% CI, 5.3 to 6.2 months) versus 4.9 months, respectively. However, the median age was 5 months for both.2 We suspect this difference would not affect the clinical outcomes between populations. The sidedness of the TTAFs and the patient sex ratio were similar in all populations.

All patients were initially presented with substantial lameness, similar to past reports.2,3,7,22 Surgical results were good to excellent, and recovery times tended to be short. Fifty percent (22/44) of our population had reached peak recovery by 42 days and 82% (36/44) by 56 days, similar to a recent abstract that reported the mean ± SD recovery time of 40 ± 14 days.7 The surgical outcomes were considered excellent by 38 of 41 owners. When asked if they would have pursued the surgery in retrospect, 39 of 41 said “yes.” This high owner satisfaction is similar to past studies.2,10

The most commonly reported breeds associated with TTAFs have been American Staffordshire Bull Terriers and Greyhounds.1,2,4,22 This is the first study to find French Bulldogs as a common breed. The authors speculate that this change in TTAF demographics may be in part due to the growing popularity of the French Bulldog, having risen from the 73rd to the second most popular breed on the American Kennel Club charts since 1999, as well as differing regional demographics. Based on the current understanding of TTAF pathophysiology, it is consistent that a highly muscular breed such as the French Bulldog would be predisposed to these injuries.2,23 What remains unclear, however, is whether this demographic difference has any bearing on surgical outcomes. Further studies are needed to evaluate whether breed or patient size influences surgical outcomes.

Limitations of our study are largely related to the retrospective and multi-institutional nature. Being retrospective, the sample size is inherently limited. An additional limitation was having multiple surgeons from different clinics, each with differing surgical techniques and follow-up. One noteworthy difference is whether or not the surgeon used a tension band for surgical repair. This is different than findings of Gower et al.,2 in which a tension band was used in all repairs with 1 or 2 K-wires.

The lack of the long-term, in-person clinical follow-up, including repeated orthopedic examination and repeated radiography after skeletal maturity, is another major limitations. This would have helped to identify any subtle long-term discomfort and lameness, an abnormally positioned patella, any distalization of the TT, and minor complications such as subtle pin migration. The reason this long-term evaluation by a surgeon or surgical resident was not pursued was due to impediments arising from the 2020 COVID-19 pandemic. Instead, we relied on client questionnaires for long-term data, which has the potential to introduce errors, especially when rating the effectiveness of the surgery. Further prospective studies with a larger population, a standardized long-term follow-up with an orthopedic examination, force plate analysis, and radiography are needed to make more valid conclusions.

Another major limitation is nonstandardized postoperative recheck times. While these rechecks were all in person, their value was limited by their high variability in follow-up times and inconsistent use of radiography. This variation also limited the usefulness in comparing the short-term outcomes with other studies. It is worth reiterating the importance of similar follow-up times to accurately compare postsurgical outcomes.

In conclusion, patients with TTAF may have similar long-term outcomes regardless of whether implants are removed early or left in situ past skeletal maturity. Clinically, this means that, unless medically necessary, patients with a TTAF repair may not need a second procedure for implant removal. This, in turn, will lower costs to owners and spare patients from the additional morbidity associated with a second procedure.

Acknowledgments
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References

Supplementary Materials

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