Atlantoaxial instability (AAI) is prevalent in toy-breed dogs and is most commonly due to a congenital malformation including dens hypoplasia or the loss of ligamentous support structures. Acquired instability, typically resulting from trauma, is less common. The instability involves the dorsal displacement of the axis (C2) relative to the atlas (C1), causing spinal cord damage. Clinical signs vary based on the extent of neurologic damage with severe cases potentially resulting in tetraparesis, respiratory failure, or death.

Treatment options include nonsurgical and surgical approaches. Nonsurgical methods employ cervical external coaptation to prevent flexion of the atlantoaxial joint. Surgical treatment aims to resolve atlantoaxial instability using patient-specific 3-D-printed drill guides and 3-D-printed titanium plates or polymethyl methacrylate (PMMA), both with the assistance of 3-D-printed drill guides.

OBJECTIVE
To report the clinical outcomes in toy-breed dogs with atlantoaxial instability (AAI) stabilized with patient-specific 3-D-printed titanium plates or PMMA, both with the assistance of 3-D-printed drill guides.

ANIMALS
15 client-owned dogs undergoing surgical treatment for AAI between January 1, 2020, and October 31, 2022.

METHODS
The clinical characteristics, diagnostic images, and neurological outcomes of 15 dogs treated for AAI using 3-D-printing technology were reviewed. Postoperative CT images were examined to evaluate the screw placement accuracy in the atlas and axis. Clinical outcomes, including postoperative neurological improvement and screw loosening, were evaluated in dogs treated with a patient-specific titanium plate and those treated with PMMA.

RESULTS
Patient-specific titanium plates (7 dogs) and PMMA (8 dogs) were used for AAI stabilization. The mean follow-up period was 15.2 months (range 7 to 22 months). A reduction of the axis without vertebral canal violation was confirmed on postoperative CT in 14 dogs. The mean deviation from the preoperative planning ranged from 0.30 to 1.27 mm at the insertion and exit points of 84 screws using this method. The neurological grade had improved in each dog postoperatively and at the final follow-up. Screw loosening was noted in 4 dogs in the titanium plates groups without neurological deterioration.

CLINICAL RELEVANCE
Patient-specific 3-D-printed drill guides and titanium plates or PMMA are effective for AAI stabilization in toy-breed dogs, providing accurate guidance.
instability directly using ventral or dorsal fixation techniques. Ventral fixation is generally preferred over dorsal fixation as it allows for arthrodesis of the atlantoaxial joint. However, ventral fixation in toy-breed dogs poses challenges due to their small vertebras and poor bone density. The reported success rate of ventral fixation in dogs ranges from 44% to 85.3% with potential complications such as implant migration, reduction failure, iatrogenic spinal cord injury, and hemorrhage.

Recently, several studies have explored the application of 3-D–printed drill guides to enhance surgical precision in neurosurgery including AAI stabilization. These studies predominantly employed polymethyl methacrylate (PMMA) for stabilization in neurosurgery. Polymethyl methacrylate–based techniques using 3-D–printed drill guides have been commonly reported in cadaver studies and have several limitations. These include challenges in maintaining C1–C2 reduction, along with issues such as soft tissue damage and compression of the upper respiratory tract. To address the complications associated with PMMA, patient-specific 3-D–printed titanium plates have been introduced as an alternative method for AAI stabilization method. Despite this advancement, there is still a lack of clinical information about patient-specific 3-D–printed drill guides with PMMA or 3-D–printed titanium plates.

This study aimed to assess clinical outcomes, postoperative complications, and the accuracy and safety of implants in toy-breed dogs treated with screws and PMMA or patient-specific 3-D–printed titanium plates for AAI stabilization using patient-specific 3-D–printed drill guides.

Methods

Cases

This retrospective study involved client-owned dogs treated between January 1, 2020, and October 31, 2022, at 2 institutions (a private referral surgical center and a university teaching hospital). Medical records of dogs were searched for an AAI diagnosis based on both CT and MRI. The inclusion criteria comprised dogs undergoing surgery for AAI using screws and PMMA or patient-specific titanium plate, both guided by patient-specific 3-D–printed drill guides. Dogs were categorized based on stabilization type (patient-specific titanium plate or PMMA). The titanium plate group utilized patient-specific drill guides and patient-specific titanium plates for ventral fixation, while the PMMA group used patient-specific drill guides and PMMA for ventral fixation. Data obtained from medical records included age of onset, body weight, sex, clinical history, neurological status at presentation and postsurgery, and surgical procedure. Neurological status grades were recorded as follows: 5, normal gait with or without neck pain; 4, ataxia; 3, ambulatory tetraparesis; 2, nonambulatory tetraparesis; and 1, tetraplegia. Additional collected data encompassed 3-D models of the patient-specific drill guide and patient-specific titanium plate, complications, and follow-up outcomes.

Fabrication of the patient-specific drill guide

For each dog, a 0.5-mm slice CT scan (Canon Aquilion Lightning 160 [Canon Medical Systems Corporation] and Alexion 16 [Toshiba Medical Systems]) of the cervical vertebral column in dorsal recumbency was acquired. Cervical spine CT data for each dog were extracted in DICOM format. The atlas and axis were separated using medical data processing software (3D Slicer, version 4.10.2; https://www.slicer.org/) and then realigned to the normal position using computer-aided design (CAD) software (3ds Max; Autodesk) (Figure 1). A patient-specific drill guide was then designed using the same CAD software. Preoperatively, we planned to insert the screws in the thickest region of the atlas and axis by confirming the 3-D reconstruction of the transverse view of the atlas and axis. We planned to insert 3 screws into C1 and 3 or 4 screws into C2. To minimize the risk of spinal cord injury, the screws placed on both ends of C1 and the cranial aspect of C2 were directed laterally, while screws placed on the caudal aspect of C2 were oriented vertically or obliquely at an angle to the ventral surface of C2 vertebral body. Additionally, to minimize the risk of spinal cord injury during screw placement in the center of C1, directed toward the spinal cord, a self-drilling screw was used. Consequently, the drill guide was designed to apply 2 screws on the ventral surface of C1, 2 screws on the cranial, and 1 or 2 screws on the caudal aspect of the ventral surface of C2. Drill guides for C1 and C2 were designed separately. To decrease the possibility of drill guide dislocation, the guide extended up to the third cervical vertebra (C3), and soft tissue interference was addressed by a window and a space between the guide and intervertebral region between C2 and C3. Two additional guide holes for the insertion of Kirschner wires (K-wires) were created on the caudolateral side of the main drill guide holes for temporary fixation, and handles for each guide were added. The drill guide holes were set to accommodate 0.8-mm K-wires for temporary fixation, 1.0-mm K-wire alongside 1.2-mm screws, and 1.2-mm K-wire alongside 1.5 screws. The drill guides were fabricated from biocompatible resin using a 3-D printing system (Pixel One; Zerone). The 3-D bone models of the atlas and axis were also fabricated from the resin using another 3-D–printing system (Shuffle XL; Phrozen) to confirm the fit of the drill guide templates to the ventral surface of the atlas and axis. A rehearsal was performed to verify the guide fit and screw location in each case. Drill guides and bone models were sterilized by hydrogen peroxide gas plasma before surgery.

Fabrication of the patient-specific titanium plate

The atlas and axis were separated for reconstruction using medical data processing software (3D Slicer, version 4.10.2; https://www.slicer.org/), and the atlantoaxial joint was realigned to the normal position by contact between the ventral articular surfaces of the atlas and axis. Reduction of the joint was confirmed using CAD software (3ds Max; Autodesk)
(Figure 1), and a patient-specific titanium plate was designed based on the realigned anatomical structure. The holes in the titanium plate were in the same trajectories as those in the drill guide. A titanium plate was printed out of Grade 23 titanium Ti-6Al-4V using a metal 3-D printer (DMP Flex 350; 3D Systems). Following thermal processing, the plate was sandblasted to make the surface uniform. The thickness of the titanium plate was 1.3 mm, and the size of the screw applied to the plate was 1.2 or 1.5 mm. In addition, a center hole of the atlas was added to apply a 1.6-mm self-drilling screw. Each titanium plate underwent plasma sterilization before surgery.

Surgical technique
In each case, a preoperative rehearsal was conducted. The depths of the drill holes were measured using a 3-D-printed vertebral bone. In the rehearsal phase, the lengths of the K-wires were marked using instrument marking tape to avoid spinal cord invasion. A drill hole, directed toward the spinal cord, was planned to be drilled using a drill bit stopper. Additionally, during the rehearsals, the lengths of the screws were premeasured to ensure the avoidance of spinal cord invasion, and the screws were applied to the 3-D-printed vertebral bone to confirm the lengths of the screws.

Cefazolin (30 mg/kg, IV) was administered 30 minutes before anesthesia and repeated every 90 minutes during surgery. Midazolam (0.1 to 0.2 mg/kg, IV) was used as a sedative, and either a fentanyl constant-rate infusion (CRI) or combined remifentanil, ketamine, and midazolam CRI was administered as an analgesic. Anesthesia was induced using propofol (6 mg/kg, IV) or alfaxalone (2 mg/kg, IV), and maintenance was achieved with isoflurane in oxygen.
All dogs were placed in dorsal recumbency, and their necks were slightly elevated and extended using towels and maintained in position using a vacuum beanbag. Ventral aspects of C1, C2, and C3 vertebrae were exposed via the standard ventral approach to cervical vertebrae as previously described. The drill guide template was attached to the ventral C1 and C2 surfaces using Mosquito forceps. K-wires were used for drilling, instead of a drill bit to temporarily fix the drill guide onto the bone, thereby preventing drill guide dislocation (Figure 2). Temporary fixation of the C1 drill guide was accomplished using 0.8-mm K-wires to minimize bone damage. The remaining screw holes were then created using 1.0-mm or 1.2-mm K-wires. To ensure precision and avoid spinal cord damage, K-wires were utilized with a drill bit stopper, particularly for drill holes with potential risk directed toward the spinal cord. The articular cartilage of C1 and C2 was removed using a bone curette. Before the application of either PMMA or a patient-specific titanium plate, a bone graft substitute (demineralized bone matrix mixed with cancellous bone; VETEREGEN Corp) was introduced into the atlantoaxial joint of each dog. In the titanium plate group, a patient-specific titanium plate was applied with 1.2-mm cortical screws (ARIX Vet; Jeil Medical Corp) to stabilize the atlantoaxial joint. Additionally, a 1.6-mm self-drilling screw (ARIX Vet) was applied to the central hole of the atlas in both groups. In the PMMA group, PMMA was used with 1.2-mm cortical screws or 1.5-mm screws (ARIX Vet) to realign the axis to the normal position. Following the application of PMMA, lavage with Hartmann solution (Ringer’s lactate) was used to protect the soft tissue from thermal injury. The surgical site was closed in a routine manner. Postoperative CT scans were utilized to evaluate atlantoaxial alignment and assess any screw invasion.

Data analyses
Postoperative assessments involved evaluating for vertebral canal violation and determining the positions of the screws in both C1 and C2. Postoperative bone models and screws were created based on postoperative CT images and imported to the 3-D CAD software to assess screw positions. The postoperative models of C1 and C2 were superimposed onto the preoperative models of C1 and C2, incorporating the planned screw positions. Screw positions were compared with planned positions by comparing insertion and exit points in the local coordinate system of the bones (X: left to right; Y: ventral to dorsal; Z: caudal to cranial directions), following a method described previously. Deviations were categorized based on their location on the vertebra. In total, 84 of the 95 screws inserted in C1, C2, and C3 were analyzed. Nine C1 center self-drilling screws were excluded from the analysis because their insertion did not use a drill guide. Additionally, 2 screws inserted at C3 in 1 dog were excluded due to their limited number.

Follow-up evaluation
Follow-up outcomes were obtained from medical records or telephone interviews with owners in cases where the dogs were unable to visit a veterinarian. At each visit, neurological grades were assessed, and plain radiographs were taken and used for evaluation of implant failures, such as screw loosening, plate dislocation, and screw or plate breakage. The complications were classified as major (surgical intervention performed) or minor (managed without surgical intervention), and the specific details of complications were noted. In cases where postoperative complications were noted, potential predisposing factors for screw loosening, such as age at onset of signs, body weight, and implant type (titanium plate vs PMMA), were compared with those in dogs without screw loosening. Short-term, mid-term, and long-term outcome evaluations were conducted at 2, 6, and 12 months postsurgery, respectively.

Statistical analyses
Statistical analyses were conducted using commercial statistical software (SPSS 28.9; IBM Corp). Continuous data (age and body weight), exhibiting

Figure 2—Representative intraoperative images of both groups. During surgery, the drill guide template was firmly attached to the ventral surface of C1 (A) and C2 (B). Patient-specific titanium plate fixed using a cortical screw (C). Use of wires to maintain reduction of the axis before applying polymethyl methacrylate (D)
nonnormal distribution, are expressed as the median value (range), and categorical data are presented as numbers (%). To assess changes in neurological status scores over time, the Friedman test was used to compare scores before, at 2 weeks, and at 4 weeks after AAI stabilization. If a significant difference was observed, pairwise comparisons with the Bonferroni correction for multiple comparisons were conducted. The association between the fixation method and screw loosening was investigated using the \( \chi^2 \) test. The relative risk (RR) with a corresponding 95% CI was calculated. Statistical significance was set at \( P < .05 \).

**Results**

**Case population**

Twenty-one client-owned dogs underwent surgery for AAI using 3-D–printed patient-specific drill guides followed by stabilization with a patient-specific titanium plate or PMMA. Records of 6 dogs that were lost to follow-up within 2 months after surgery or had died from unrelated causes were excluded. The remaining 15 dogs were categorized based on stabilization type: patient-specific titanium plate (n = 7) or PMMA (8). Six were castrated males, 1 was male, 4 were females, and 4 were spayed females. The median age at onset was 17 (range, 3 to 85) months, and the median age at first presentation of clinical signs was 17 (range, 8 to 88) months. The mean body weight was 2.4 (range, 0.6 to 3.6) kg. Associate radiographic findings were hypoplastic dens (8 dogs [53%]), dorsally deviated dens (6 dogs [40%]), and dens fracture (1 dog [6%]). The clinical characteristics of each dog are summarized (Supplementary Table S1).

**Positioning and accuracy of the 3-D–printed drill guides**

One screw was inserted on the left and another on the right side of C1 for each dog. An additional screw was inserted in the center of C1, 2 in the cranial aspect of C2, and either 1 or 2 in the caudal aspect of C2 depending on the dog’s size. In total, 84 of the 95 screws were analyzed. The mean deviation, which is the difference between the position planned before surgery and the actual position applied after surgery, ranged from 0.30 to 1.27 mm for each axis of the insertion and exit points of the 84 screws inserted in C1 and C2 (Supplementary Table S2).

**Neurological grade**

Neurological status of each dog is summarized (Supplementary Table S3). At the initial presentation, the median neurological status score was 3 (range, 2 to 4), with 7 dogs scoring 2, 7 dogs scoring 3, and 1 dog scoring 4. All dogs were managed with a neck brace until surgical stabilization, resulting in improvement for 4 dogs. The median scores immediately before surgical AAI stabilization and at 2 and 4 weeks after stabilization were 3 (range, 2 to 4), 4 (range, 3 to 5), and 5 (range, 4 to 5), respectively. Over time, there was a significant change in scores (\( P < .001 \)). In comparison to the preoperative status, there was a significant improvement in neurological status at 2 weeks (\( P = .032 \)), and 4 weeks (\( P < .001 \)) following surgical stabilization. The neurological status score further improved from 2 to 4 weeks postoperatively. However, the improvement between the 2 and 4 weeks postoperative periods did not reach statistical significance (\( P = .067 \)).

Fourteen dogs were included in 2- and 6-month follow-up assessments, which encompassed examinations conducted by veterinarians and radiologists. Additionally, 12 dogs were included in the follow-up assessment for 12 months or more. In the 6-month follow-up, 11 dogs displayed normal gait and the neurological grades remained unchanged compared to those at the 2-month follow-up except in 1 dog. In dog 1, the neurological grade deterioration from 5 to 3 without evidence of surgical failure in the repeat CT, which was also identified to be a quadrigeminal cyst unrelated to the AAI surgery. In the final assessment, the neurological grade and gait were unchanged compared with those at the 6-month follow-up.

**Intraoperative and postoperative complications**

No intraoperative complications occurred. Through postoperative CT, the atlas and axis were confirmed to be well aligned in all dogs (titanium plate group and PMMA group; Figure 3). The length of the screws was too long and vertebral canal violation was observed on postoperative CT in only 1 dog (dog 1; Supplementary Table S3). Postoperative CT images revealed adequate alignment of the atlas and axis, but the right C1 and C2 screws were inserted into the vertebral canal in dog 1. Revision surgery was immediately performed. One screw in C2 was removed, another screw in C1 was changed to a shorter screw, and CT confirmed that the screws had not invaded the vertebral canal. Additionally, postoperative CT revealed that a C1 screw was laterally misplaced in dog 7. However, vertebral canal violation was not observed, and the atlas and axis were well aligned. Therefore, revision surgery was not performed.

In the perioperative period, the status of the implants was monitored by examining cervical radiographs. There were minor complications in 3 dogs (dogs 1, 2, and 3) and a major complication necessitating revision procedures in 1 dog (dog 7) (Supplementary Table S3). In the 3 dogs with screw loosening, the alignments of C1 and C2 were appropriately maintained based on radiographs. In 1 dog (dog 7), a dislocated plate was confirmed based on radiographs at 2 weeks postoperatively, and the plate was removed and replaced with screws and PMMA. Out of the 93 screws inserted in either C1 or C2, 12 screws exhibited loosening in 4 dogs within the first 2 months postoperatively. Specifically, 18% of the screws placed in C1 (7 out of 39) and 9% in C2 (5 out of 54) were found to be loose. Despite the higher percentage of loosening in C1, there was no statistically significant association between the cervical vertebra and screw loosening (RR = 1.9; 95% CI [0.67 to 5.7]; \( P = .22 \)). Of the total 93 screws,
61 were utilized in conjunction with plates, and 52 were used with PMMA. All 12 screw loosening occurred exclusively in cases stabilized with a plate, and a significant association was found between the plate and screw loosening ($P < .001$). Compared with the plate, PMMA demonstrated a higher likelihood of providing more stable fixation (RR = 1.4; 95% CI [1.2 to 1.7]).

The median age and body weight of dogs that experienced screw loosening were not different from those without screw loosening, with $P$ values of .9 and .36, respectively. The neurological status score of individuals with screw loosening significantly improved over time ($P < .001$). Specifically, the score (median = 5) at the 4-week postoperative follow-up was significantly higher than the preoperative score (median = 3) ($P = .02$). In contrast, the score (median = 4) at the 2-week postoperative recheck was not different from the preoperative score ($P = .34$) in those cases.

**Figure 3**—Pre- and postoperative 0.5-mm-slice CT images of atlantoaxial joint of 4 dogs (A–C; dog 6, D–F; dog 10, G–J; dog 4). Preoperative sagittal plane CT image of dog 6 (titanium group) (A). The surgery was performed using a patient-specific drill guide and a patient-specific titanium plate. Postoperative sagittal plane CT image confirmed reduction of C2 (B). 3-D reconstruction of postoperative CT image in dog 6 (titanium group) (C). Preoperative sagittal plane CT image of dog 10 (polymethyl methacrylate [PMMA] group) (D). Postoperative sagittal plane CT image confirmed reduction of C2 using the patient-specific drill guide and PMMA (E). The 3-D reconstruction of postoperative CT in dog 10 (PMMA group) (F). Pre- and postoperative dorsal plane CT images of dog 4 (G–J). Dorsal view preoperative CT (G; arrow, dens). Postoperative CT confirmed a well-aligned atlantoaxial joint without compression of the spinal cord (H; arrow indicates the dens). In the 3-D planning, simply applying reduction of C2 (yellow region) and the dens (arrow) resulted in spinal cord compression after reduction (I). In the 3-D planning, that reduction was applied after C1-C2 distraction and rotation, and atlantoaxial joint was well aligned and the dens (arrow) were not compressing the spinal cord (J).
Accuracy of screw placement is important to reduce iatrogenic spinal cord injury and increase surgical success in AAI treatment. Several studies have shown that 3-D–printed drill guides provide enhanced accuracy for screw placement in neurosurgery. In our study, 93% (14/15) of the dogs safely underwent surgery without perioperative complications, including vertebral canal invasion. Moreover, no complications related to spinal cord injury were observed during this study. Notably, atlantoaxial joint stabilization was successfully performed without complications even in a 600-g Maltese, despite the challenges of AAI surgery in toy-breed dogs. Additionally, the neurological status and gait of 11 dogs (11/14, excluding dog 7 due to revision surgery) were nearly normal within 1 month after AAI stabilization. These results suggest the patient-specific drill guide technique is an effective and safe option for AAI stabilization.

In this study, we retrospectively investigated the accuracy of patient-specific drill guides. To evaluate the accuracy of patient-specific drill guides, deviations, which are differences between the position planned before surgery and the actual position applied after surgery, in screw insertion and exit points were analyzed. Our analysis showed errors of less than 1.3 mm on average for screws at all aspects of C1 and C2. Considering the clinical outcomes and following comparison with the results of a previous study,6 which also reported an error of less than 2 mm on average for each axis, our guide system provided a clinically acceptable function. However, the average deviation of the caudal C2 screw insertion points exhibited an outstanding mediolateral error (on the x-axis, 0.92 ± 0.92 mm). We believe that the higher error was related to the oblique insertion angle of the screw, because it was not observed in the vertical application (on the x-axis, 0.14 ± 0.02 mm). Indeed, 1 report revealed that using a relatively low angle for screws leads to lower accuracy and higher deviations due to the lack of a flat drilling surface. Despite this error, the screw deviations observed in our study were still acceptable when compared to those of other studies.6 Our study suggests that patient-specific drill guides provided accurate guidance for screws and the error can be further minimized by achieving a vertical screw angle.

We also investigated clinical outcomes and perioperative complications, and no serious intraoperative complications occurred in this study. The primary postoperative complication was screw loosening. Only 1 dog underwent revision surgery among the 4 dogs with screw loosening. The atlantoaxial joint was well aligned and improvement of neurological status was maintained in the other 3 dogs; thus, additional surgery was not needed. We speculated that the sustained improvement in neurological status and the maintenance of a normal atlantoaxial angle in dogs with screw loosening result from the fact that the atlantoaxial joint is not a weight-bearing structure and is influenced by fibrosis of surgical region tissues. Furthermore, we considered screw loosening to be related to the use of a K-wire for drilling. We believed that dislocation of the drill guide could cause critical complications and drilling with a K-wire was easily feasible due to the dog's small vertebrae; thus, we used a K-wire for drilling. However, 12 screws out of 93 loosened, prompting us to consider the potential impact of using a K-wire instead of a drill bit. Additionally, we noted screw loosening was associated with the fixation method, given that it occurred only in the titanium plate group. Plate fixation stability depends on screw tightening, creating friction with the bone. Therefore, shear force at the plate-bone interface, resulting from motion, can lead to screw loosening, especially in bone with poor quality, thin cortex, and short working length.21 In the present report, compression bending on the ventral aspect of C1 and C2 of toy-breed dogs could have caused micromotion and shear, leading to screw loosening. In contrast, there was no screw loosening observed in AAI stabilization with screws and PMMA that is independent of friction. Additionally, PMMA gripped the screws, ensuring stability similar to a locking plate. Several neurosurgery studies have reported using a locking plate system to reduce screw loosening. We believe that using a locking plate system instead of the conventional plate system could reduce implant loosening complications; however, manufacturing locking thread holes in 3-D–printed titanium plates is challenging. Therefore, developing techniques for designing and manufacturing locking plate systems using 3-D–printing technology is required to advance the use of patient-specific plates in the future. Until the locking plate system was introduced, PMMA was superior to 3-D–printed patient-specific titanium plates for firm fixation in AAI surgery in our study.

Maintaining C1–C2 reduction for normal alignment is challenging in conventional ventral stabilization of AAI.3 Consequently, the patient-specific implant could offer benefits for optimal alignment in neurosurgery. The patient-specific implant could be precontoured to fit the C1–C2 reduction and set specific angles or alignment between vertebrae. In our study, C1–C2 reduction was particularly challenging in dog 4. In dog 4 with severe dens deformity, it was recognized that simply conducting an atlantoaxial joint reduction might exert the risk of persistent compression of the spinal cord by the deformed dens. Surgical procedures such as C1–C2 osteotomy, C1–C2 distraction and fixation, and odontoidectomy, which are commonly required in dogs with dens deformity, are associated with a high risk of spinal cord injury.3 Thus, we designed the patient-specific titanium plate to enable C1–C2 distraction and rotation for reduction of the atlantoaxial joint without spinal cord compression (Figure 3). This approach facilitated accurate reduction of the atlantoaxial joint, even without odontoidectomy in dog 4. Therefore, we consider the use of patient-specific titanium plates, which are precontoured as desired, can aid in the reduction and normal alignment in AAI surgery.
The main limitations of this study were its retrospective nature and small cohort of dogs. Due to the limited number of dogs, there are insufficient data to draw clinically relevant conclusions. Moreover, there was no control group in the accuracy analysis of patient-specific 3-D-printed drill guide. Further studies are warranted to compare a freehand technique and a patient-specific drill guide in analyzing drill guide accuracy.

In conclusion, the patient-specific 3-D-printed drill guide can provide accurate guidance for AAI stabilization in toy-breed dogs, and PMMA drill guide can provide accurate guidance for drill guide accuracy. The prospective nature and small cohort of dogs. Due to the retrospective nature and small cohort of dogs, there were no control groups in the accuracy analysis to draw clinically relevant conclusions. Moreover, the authors have nothing to disclose.

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**References**


**Supplementary Materials**

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