https://doi.org/10.17221/18/2018-VETMED

Evaluation of the efficiency of the C-ring aiming guide for atlantoaxial transarticular screw fixation in toy breed dogs

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Citation: Park JY, Kim YR, Choi HJ, Lee YW, Jeong SM, Lee HB (2019): Evaluation of the efficiency of the C-ring aiming guide for atlantoaxial transarticular screw fixation in toy breed dogs. Veterinarni Medicina 64, 18–24.

Abstract: The goal of the present study was to evaluate the efficiency and safety of the C-ring aiming guide for the atlantoaxial transarticular screw fixation technique in toy breed dogs. Twenty-one adult canine cadavers of toy breed dogs were used in this study. The left and right sides of the cervical vertebrae were randomly assigned to two implant insertion groups: a C-ring aiming guide group and a drill guide group. A 1.2-mm Kirschner wire was inserted into each side by using either a C-ring aiming guide or a drill guide. CT scans were performed before and after surgery. The optimal safe implantation corridor angle and length, the implant insertion angle and length, the implant insertion time and the proportion of the insertion corridor to the optimal corridor were evaluated. Violations to the alar foramen and the vertebral canal also were evaluated. The implant insertion time was twice as long as that observed in the aiming guide group ($P < 0.05$). The proportion of the insertion angle and length to the optimal angle were not significantly different between groups ($P > 0.05$). With respect to precision, there was a trend toward less variability in the aiming guide group; however, this difference was not significant ($P = 0.09$). The violation of the alar foramen was significantly lower in the aiming guide group than in the drill guide group ($P < 0.05$). Violation to the vertebral canal was detected in one cadaver in the drill guide group but did not occur in the aiming guide group. The use of a C-ring aiming guide was associated with less damage to the alar foramen and the vertebral canal during atlantoaxial transarticular screw fixation in toy breed dogs.

Keywords: atlantoaxial instability; ventral stabilisation technique; vertebral foramen; cadaver; Kirchner wire

Atlantoaxial (AA) joint instability is a congenital or developmental disorder which commonly occurs in immature toy breed dogs, including Yorkshire Terriers, Chihuahuas and Toy Poodles (Plessas and Volk 2014). Malformation of the odontoid process is the most common cause of AA joint instability. Ligament dysplasia, incomplete ossification of the atlas and traumatic injuries can also result in instability of the AA joint (Warren-Smith et al. 2009; Plessas and Volk 2014). Dorsal displacement of the axis due to AA joint instability results in acute or chronic spinal cord compression. Associated clinical signs may range from cervical pain to tetraplegia and even death.

Surgical treatment of AA joint instability can be broadly divided into dorsal or ventral stabilisation

Supported by the Basic Science Research Program through the National Research Foundation of South Korea funded by the Ministry of Education, Science and Technology, Republic of Korea (Grant No. NRF-2015R1D1A1A01056945).

https://doi.org/10.17221/18/2018-VETMED

techniques. Dorsal stabilisation techniques, such as AA wiring, dorsal cross pining and the Kishigami AA tension band are mostly dependent on the formation of fibrous tissue and generally cannot produce osseous fusion at the AA joint. Thus, implant failure and loss of stabilisation are more likely to occur (Thomas et al. 1991). Ventral stabilisation techniques such as transarticular screws and pins and polymethylmethacrylate stabilize the AA joint by fusing the atlas and the axis. These techniques also facilitate anatomical alignment, complete reduction and strong fixation, which result in lower implant failure compared to dorsal stabilisation techniques (Platt et al. 2004).

The transarticular screw fixation technique is one type of ventral stabilisation technique. It is a useful surgical technique that is used to stabilise AA joint instability. However, this technique is a very challenging procedure. Due to the small size of the affected dogs and the extremely narrow bone corridors used to position stabilising implants, this technique is very demanding and often allows only one attempt for screw insertion (Platt et al. 2004; Vizcaino Reves et al. 2013). As the decision of the screw insertion angle is based on the surgeon's experience in surgery rather than on a best-practice protocol, variations in outcomes and serious complications can often occur following transarticular screw fixation. Complications resulting directly from such narrow bone corridors include injury to the vertebral canal, spinal cord, vertebral foramen and vertebral artery; moreover, high mortality rates (10–44%) have also been reported (Jeserevics et al. 2008; Hettlich et al. 2013). Thus, a more accurate and safer method for transarticular screw insertion is required.

The aiming guide is commonly used for coxofemoral luxation repair (Kieves et al. 2014). An aiming guide is an instrument used to guide a drill or pin placement. After placing the sharp pointed tip of the aiming guide on the desired exit point, the drill or pin is advanced into the inner sleeve of the aiming guide toward the sharp pointed tip. Finally, a pin or drill comes out at the desired exit point. The correct trajectory can be achieved using the aiming guide.

The purpose of this study was to evaluate the efficiency of the C-ring aiming guide compared with that of the common technique of using a drill guide for the transarticular screw fixation technique in toy breed dogs. We hypothesized that the use of a C-ring aiming guide would be safer and more accurate than the general method in transarticular screw fixation.

MATERIAL AND METHODS

Specimens and groups. Twenty-one adult canine cadavers from toy breed dogs, which were euthanised for reasons unrelated to this study, were obtained. This study was approved by Chungnam National University Animal Care and Use Committee (No. CNU-0838).

None of the dogs had a history of cervical spine disease. The following breeds were included in this study: Mongrel (n = 13), Poodle (n = 4), Maltese (n = 1), Shih-tzu (n = 1), Pekingese (n = 1) and Miniature Pinscher (n = 1). In total, there were nine males and 12 females. The mean weight was 4.2 kg (range, 2.0–6.4 kg).

The cadavers were stored at −20 °C and thawed at room temperature for 24 hours before the procedure. The cadavers were positioned in dorsal recumbency and placed with the neck in extension. The paramedian approach to the atlantoaxial joint was performed. The longus colli muscle that was close to the sharp ventral prominence on the caudal aspect of the atlas was transected. Muscles from the ventral arch of the atlas and the body of the axis were elevated caudolaterally, exposing the atlantoaxial joint and axial body (Figure 1A). The joint space was opened, and an odontoidectomy was performed using a sagittal saw to make an artificial AA instability model (Figure 1B). The left and right sides of the cervical vertebrae were randomly assigned to two implant insertion groups using a computer software program (Microsoft Excel, Microsoft, USA): one group used the C-ring aiming guide (Bio-Compression Screw C-Ring Guide, Arthrex, USA), and the other group used a drill guide (1.2 mm drill guide, BS. Corem, Republic of Korea) for the ventral transarticular screw fixation technique.

Surgical procedure. All of the surgical procedures were performed by one surgeon (HBL). The surgeon's experiences with the transarticular screw fixation technique included approximately 50 AA joint instability procedures in toy breed dogs. The drill guide was used on one side according to a randomly assigned order. The transarticular screw fixation technique was performed

https://doi.org/10.17221/18/2018-VETMED

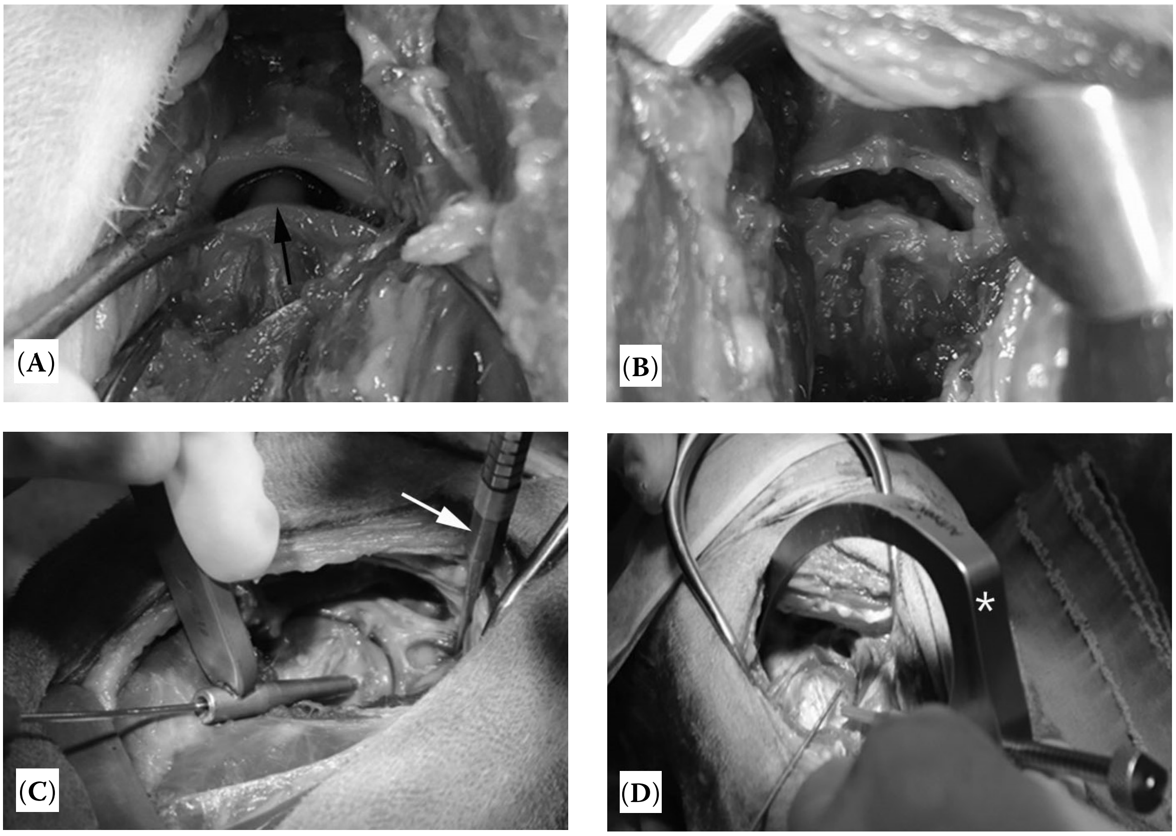

Figure 1. The atlantoaxial joint space was opened and the dens were visible (black arrow) (**A**). An odontoidectomy was performed to induce instability between the atlas and the axis (**B**). A periosteal elevator (white arrow) was placed on the alar notch for the direction guide (**C**). The Kirschner wire was inserted at the deepest point of the pit medial to the cranial end of the crest. The C-ring aiming guide (asterisk) was used on the other side (**D**)

as described previously by Vizcaino (2013). A small hole was made by a pneumatic burr to prevent the Kirschner wire from slipping in the deepest point of the cranial ridge of the ventral aspect of the axis. The muscle was carefully elevated from the ventral aspect of the atlas toward the alar notch using a periosteal elevator. Then, a periosteal elevator was placed on the alar notch for the direction guide. Next, a 1.2-mm Kirschner wire was inserted into the 1.2-mm drill guide, and the tip of the Kirschner wire was placed on the hole of the axis (Figure 1C). Then, the Kirschner wire was drilled toward the alar notch, as indicated by the periosteal elevator. The C-ring aiming guide was used on the other side. A pointed tip of the guide was placed on the alar notch (Figure 1D). The 1.2-mm Kirschner wire was inserted into the sleeve of the aiming guide, and the tip of the Kirschner wire was placed on the previously made hole of the axis by adjusting the direction of the aiming guide. Next, the Kirschner wire was drilled from the axis to the end point of the aiming guide. The procedure time was measured for each group. After the procedure, the cadavers were placed in the freezer (−20 °C) for 48 hours without the removal of the Kirschner wires.

CT scan techniques. A CT scan was performed twice. The first CT scan was performed before the surgical procedure to evaluate the individual optimal corridor for the transarticular screw fixation technique, and a second CT scan was performed after the surgical procedure to compare and evaluate each group. In the second CT scan, frozen cadavers were used after the removal of the Kirschner wires to prevent the occurrence of an artefact. The cadavers were positioned in sternal recumbency with both of the front limbs extended cranially on the CT table and scanned using a 32-detector-row CT scanner (Alexion™, Toshiba, Japan) using the following parameters: 120 kVp, 150 mAs, 1-mm slice thickness, 1-s rotation time and 0.938 collimation beam pitch. The images were reviewed us-

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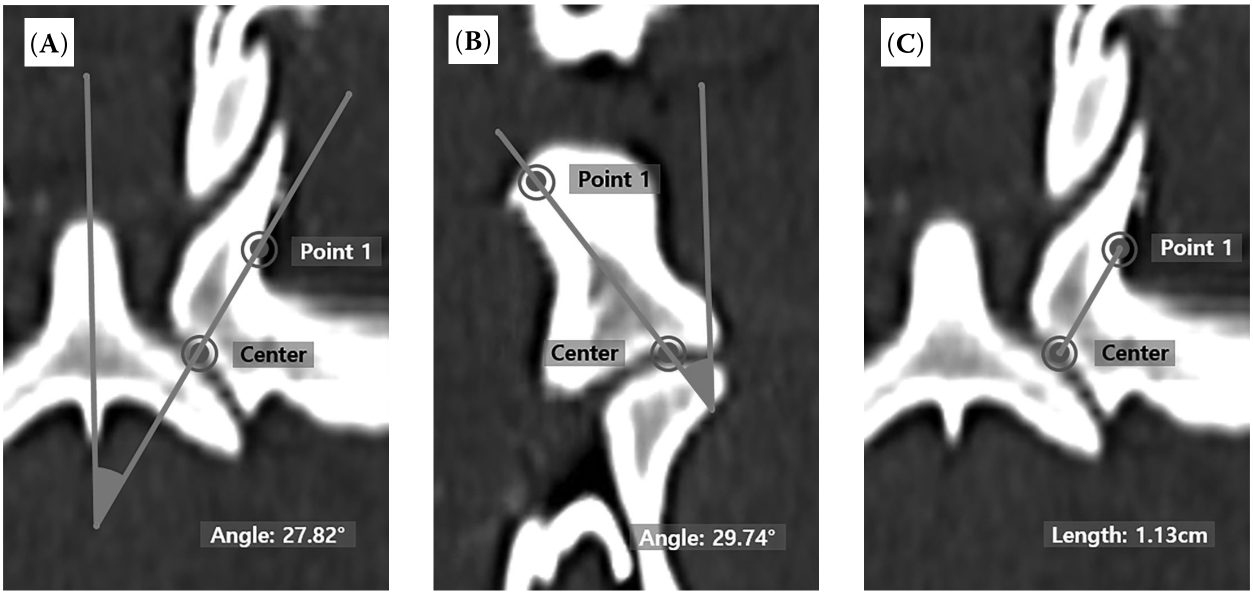

Figure 2. The optimal corridor angle and length were measured in the 3D-MPR mode. The mediolateral angle was measured laterally from the midline along the dorsal plane, (**A**) and the ventrodorsal angle was measured dorsally from the floor of the neural canal of the axis along the sagittal plane (**B**). The corridor length was obtained by measuring the distance between point 1 and the centre point (**C**)

ing the window width and level preset in OsiriX™ (OsiriX^{TM}, Pixmeo SARL, Switzerland) for the bone CT images in the 2D viewer, the 3D multiplanar reconstruction (MPR) and the 3D volume rendering (VR) modes.

Determination of an optimal safe implantation corridor. The optimal safe implantation corridor (OSIC) was evaluated as described previously by Leblond (2016) (Figure 2).

Evaluation of the implant corridor. The mediolateral and ventrodorsal angles were measured using CT imaging. The inserted implant length was obtained by measuring the distance between the caudal articular surface of the atlas and the oppo-

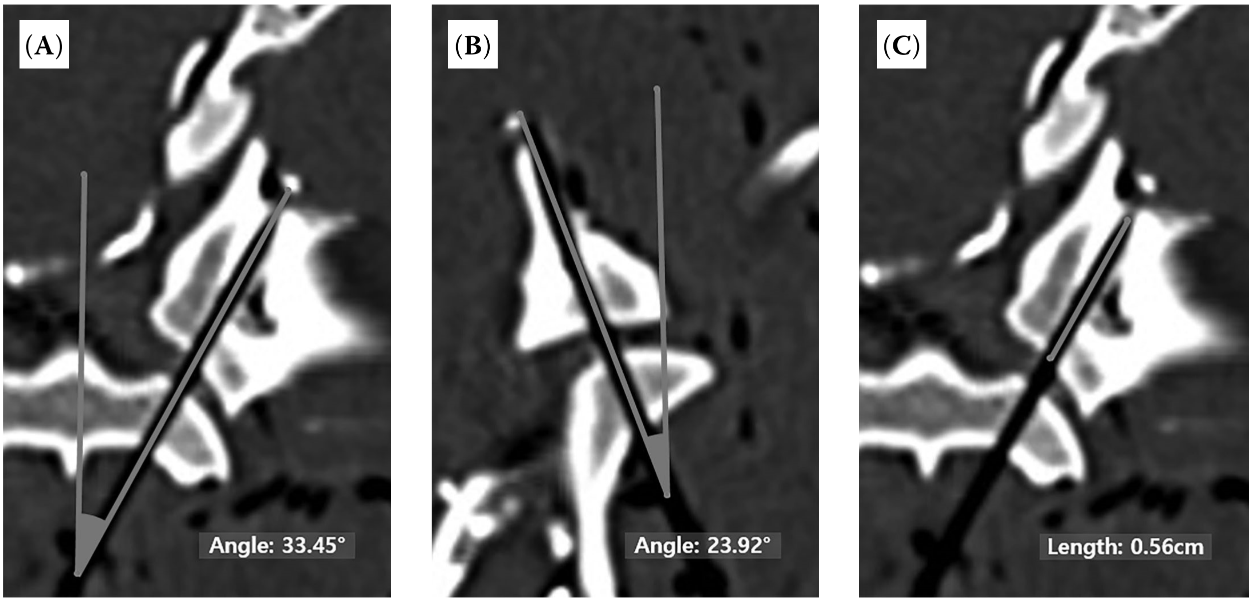

Figure 3. The mediolateral angle (**A**), ventrodorsal angle (**B**) and implant length (**C**) were measured using the air shadowing passed by the Kirschner wire

https://doi.org/10.17221/18/2018-VETMED

site cortex along with air shadowing. In addition, a violation to the alar foramen was also evaluated in the 3D-VR mode (Figure 3).

Statistical analysis. All statistical analyses were performed using SPSS software version 22.0 (IBM SPSS Statistics 22.0, IBM Corp., USA). The data were compared using a 2-sample *t*-test (mediolateral angle) or the Mann-Whitney *U*-test (ventrodorsal angle, insertion length, procedure time) as appropriate, based on data normality. $P < 0.05$ was considered significant. The χ^2 test was used to compare the statistical significance ($P < 0.05$) of differences between groups in violations of the alar foramen.

RESULTS

Optimal safe implantation corridor angles and length

The mean ± SD optimal angles were 26.05 ± 5.12° lateral from the midline in the dorsal plane and 28.98 ± 4.32° dorsal from the neural canal in the sagittal plane. The mean ± SD optimal length was 10.98 ± 1.16 mm.

Implant insertion angle

The mean mediolateral and ventrodorsal angles of the inserted implant were each larger than the optimal angle of each of the two groups. The mediolateral angles of the aiming guide group and the drill guide group were 33.34 ± 2.66° and 31.35 ± 3.47°, respectively. The ventrodorsal angle of the aiming guide group and the drill guide group were 24.21 ± 5.51° and 24.42 ± 5.18°, respectively (Table 1). There were no significant differences between the groups ($P > 0.05$). With respect to the precision observed in both groups, there was a trend toward less variability in the aiming guide group; however, this difference was not significant ($P = 0.09$).

Implant insertion length

The mean inserted length was approximately one-half of the optimal length for the two groups. The inserted lengths of the aiming guide group and the drill guide group were 5.35 ± 3.38 mm and 5.53 ± 2.53 mm, respectively (Table 1). There were no significant differences between the groups ($P > 0.05$).

Implant insertion time

The mean time required for insertion of the Kirschner wire was twice ($P < 0.05$) as long in the aiming guide group compared to the drill guide group (Table 1).

Violation of the alar foramen and vertebral canal

The Kirschner wire penetrated the alar foramen by 11.7% in the aiming guide group and 48.4% in the drill guide group (Table 1). The violation of the alar foramen was significantly lower in the aiming guide group than in the drill guide group ($P < 0.05$). Violation of the vertebral canal was detected in one cadaver in the drill guide group but did not occur in the aiming guide group.

DISCUSSION

Precise screw insertion is highly important for increasing the success rate and reducing the number

Table 1. Measured values (mean ± SD) of the insertion angle, length, time and violation to the alar foramen

	Insertion angle		Insertion length (mm)	Insertion time (s)	Violation to alar foramen
	mediolateral angle	ventrodorsal angle			
Aiming guide	33.34 ± 2.66°	24.21 ± 5.51°	5.35 ± 3.38	272.13 ± 147.58*	11.7%*
Drill guide	31.35 ± 3.47°	24.42 ± 5.18°	5.53 ± 2.53	141.13 ± 46.27*	48.4%*
P-value	0.107	0.911	0.368	< 0.001	< 0.05

*Value indicates significant difference between two groups ($P < 0.05$)

https://doi.org/10.17221/18/2018-VETMED

of complications during surgery for transarticular screw fixation. This study showed that the use of a C-ring aiming guide resulted in significantly less damage to the alar foramen and the vertebral canal during transarticular screw fixation compared with the drill guide. With respect to the precision observed in both groups, there was a trend toward less variability in the C-ring aiming guide group; however, this difference was not significant.

The success rate of the transarticular screw fixation technique has been reported as 71% (44–90%), and the mortality rate has been reported as 22% (10–44.4%) (Beaver et al. 2000; Jeserevics et al. 2008). Surgical complications include implant failure, spinal cord injury, respiratory problems and cardiac arrest. The OSIC has been tested for safer screw insertion, and the alar notch has been subsequently reported as a common landmark for optimal transarticular screw fixation (Aikawa et al. 2013; Leblond et al. 2016).

The mean optimal mediolateral angle was 26.05° when the individual OSIC was measured in this study. However, there was a difference in this angle for each individual (20–31°). A previous study reported that the mean optimal mediolateral angle was 40° (Vizcaino Reves et al. 2013). Therefore, it may not be ideal to use the mean optimal mediolateral angle when using the drill guide method, as has been reported for the transarticular screw. To overcome these individual differences when performing the surgery using the drill guide method, it may be ideal to obtain the patient's optimal corridor via a CT scan and to adjust and maintain the patient in the correct position on the operating table (Kazan et al. 2000). However, if the implant can be accurately inserted into the medial border of the alar notch, which is a landmark for optimal transarticular screw fixation, a CT scan may not be needed to determine the optimal safe implant corridor. Furthermore, the effort required to maintain the correct position of the patient during surgery may be avoided. Therefore, there may be an advantage to using the aiming guide when inserting the transarticular screw, as the correct trajectory can be achieved.

In this study, there was no significant difference between the implant insertion angle and implant length when comparing groups using the aiming guide and the drill guide. The precision of the mediolateral angle was likely higher in the aiming guide group compared to the drill guide group. This may be related to the difficulty in accurately positioning the end point of the aiming guide on the flat anatomy of the alar notch due to the sharp structure of the end point of the aiming guide. This process required more than twice the length of time in the aiming guide group compared to the drill guide group. The C-ring aiming guide used in this study is a product that has been applied to human wrist and ankle surgery procedures and involves the connection of a round and large body part to the end point. Thus, the process took more time in this surgery because it was not easy to access the small dog's alar notch, and it was difficult to fine-tune the guide. Therefore, a limitation in this study was that a device that is used on humans was applied to small dogs. Based on the results of this study, it would be possible to take advantage of the characteristics for establishing the exit point and develop an aiming guide adjusted to the size of small dogs that can guide the insertion of implants into the medial border of the alar notch, thereby achieving better results in the transarticular screw fixation technique. However, additional studies on the modified aiming guide are required to further determine whether it is suitable for toy breed dogs.

Invasion of the alar foramen was significantly lower in the aiming guide group than in the drill guide group. Invasion of the alar foramen may induce damage of the vertebral artery, which can result in spinal cord ischaemia. This situation may also worsen neurological deficits. However, as this was a cadaveric experiment, vascular damage was difficult to quantify in this study. Furthermore, even though there was vascular damage, worsened outcomes or delayed recovery time of the neurological deficits that are normally associated with vascular damage could not be evaluated because the study was performed on cadavers. Further studies are needed to assess the clinical significance of this type of damage. Damage to the vertebral canal was detected in one cadaver in the drill guide group but did not occur in any of the cadavers in the aiming guide group. Damage to the vertebral canal can cause spinal cord injury. Therefore, this situation should be avoided during the transarticular screw fixation technique. The results obtained in this study indicate that use of the aiming guide can avoid injury to the vertebral canal and to the alar foramen, as the correct trajectory can be achieved.

The experimental design of our study has limitations. We used normal dog cadavers without AA

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joint instability, although the AA joint instability model was created by an odontoidectomy. The transarticular screw fixation technique may be more difficult due to fibrosis in various anatomical deformities of the atlas and the axis.

Ventral transarticular screw fixation of the atlantoaxial joint is very challenging and requires perfect placement within a very small target area. The use of a C-ring aiming guide was associated with less damage to the alar foramen and the vertebral canal during the atlantoaxial transarticular screw fixation surgical procedure in toy breed dogs.

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Received: February 4, 2018
Accepted after corrections: November 12, 2018