

## The use of a pin-screw-wire tie-in configuration for ventral stabilization of congenital atlantoaxial instability in a Yorkshire terrier

*Het gebruik van een pin-schroef-ijzerdraad-“tie-in”-configuratie voor ventrale stabilisatie van aangeboren atlantoaxiale instabiliteit bij een yorkshire terriër*

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### ABSTRACT

A one-year-old Yorkshire terrier of 1.2 kg was presented with an eight-month-old history of non-ambulatory tetraparesis. The dog was diagnosed on right-lateral radiography with atlantoaxial instability (AAI). Ventral stabilization was achieved with a tie-in configuration. Two 0.9-mm-positive-profile-threaded pins and four 1.2-mm-locking screws were inserted into the atlas and the axis, respectively. The pin shafts were bent caudally and tied in with the screws using cerclage wire. Polymethylmethacrylate (PMMA) was applied to the entire construct. The dog showed rapid improvement after surgery, walking on his own on day three, postoperatively. There were no complications related to the surgery. This adjusted multiple implant fixation technique using pins, screws and cerclage wire embedded in PMMA in a tie-in configuration can be a feasible option to provide rigid fixation for AAI in toy breed dogs.

### SAMENVATTING

Een één jaar oude yorkshire terriër met een gewicht van 1,2 kg werd aangeboden met tetraparesis die reeds acht maanden aanwezig was. Tijdens het radiografisch onderzoek werd atlantoaxiale instabiliteit (AAI) gediagnosticeerd. Ventrale stabilisatie werd bekomen met een “tie-in”-configuratie. Twee 0,9 mm-pinnen met positieve schroefdraadprofielen en vier 1,2 mm “locking”-schroeven werden in respectievelijk de atlas en axis ingebracht. De pinnen werden naar caudaal omgebogen en vastgemaakt aan de schroeven middels cerclagedraad, waarna de gehele constructie werd ingebed in een brug van polymethylmethacrylaat. De hond vertoonde een snel, klinisch herstel en liep zelfstandig op dag 3 na de chirurgische ingreep. Er waren geen postoperatieve complicaties. Deze aangepaste techniek van fixatie met meerdere implantaten in een “tie-in”-configuratie kan een haalbare optie zijn voor AAI bij kleine hondenrassen.

### INTRODUCTION

In young and toy breed dogs, ventral stabilization of atlantoaxial instability (AAI) is technically challenging because of the extremely narrow bone corridor for implant placement and relatively soft bone, even though it provides the most rigid fixation for the atlantoaxial joint (AAJ) (Platt et al., 2004; Vizcaíno Revés et al., 2013; Pujol et al., 2010; Stalin et al., 2015). These limitations are associated with high risks

of surgical complications including implant failure, implant invasion into the vertebral canal causing iatrogenic spinal cord damage, and iatrogenic bone fracture, leading to relatively high mortality rates (5-30%) (Slanina, 2016; Thomas et al., 1991). To overcome these limitations, several dorsal stabilization techniques, providing easy handling of the atlantoaxial bone via a dorsal approach, have been introduced for toy breed dogs with AAI. (Jeffery et al., 1996; Pujol et al., 2010 ; Sánchez-Masian et al., 2014; Riedinger et

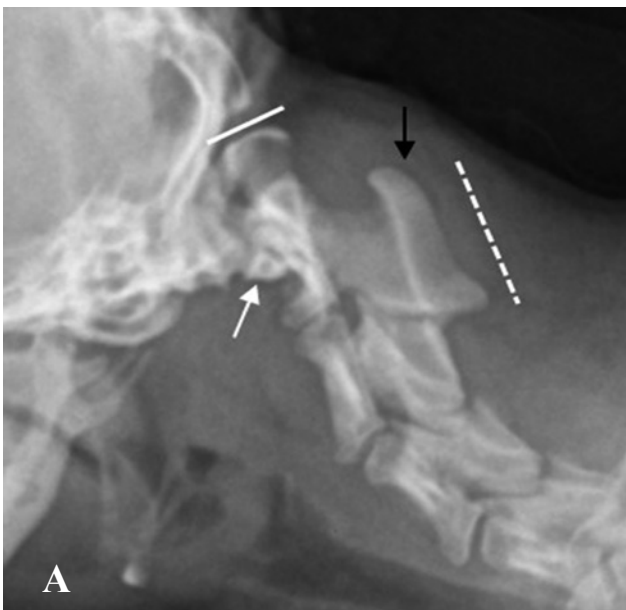
al., 2015; Stalin et al., 2015). However, dorsal stabilization also has several disadvantages: first, implants can become unstable over the long term because permanent fixation via arthrodesis cannot be achieved with this technique. Secondly, accurate axis (C2) reduction is not possible if there is a significant amount of thick fibrous tissue in the AAJ due to chronic lesions. Therefore, in cases of toy breed dogs with chronic and congenital AAI with atlantoaxial malformation, ventral stabilization is still considered as the primary approach, with various ventral stabilization techniques constantly being developed to resolve its limitations (Platt et al., 2004; Dickomeit et al., 2011; Aikawa et al., 2013; Sánchez-Masian et al., 2014).

In this case report, a technique of ventral stabilization using a tie-in configuration consisting of positive-profile threaded pins, screws, wires, and polymethylmethacrylate (PMMA) is described for the correction of congenital and chronic AAI in a Yorkshire terrier.

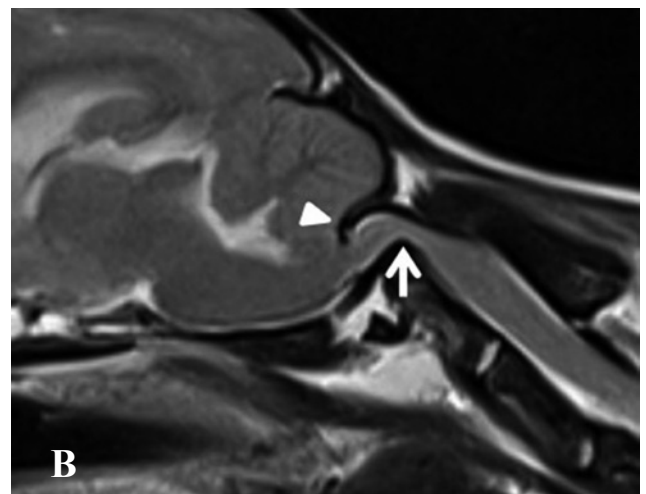
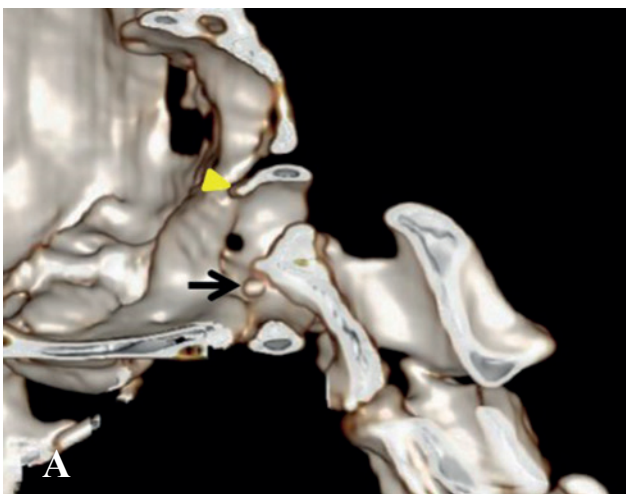
## CASE REPORT

### History and diagnosis

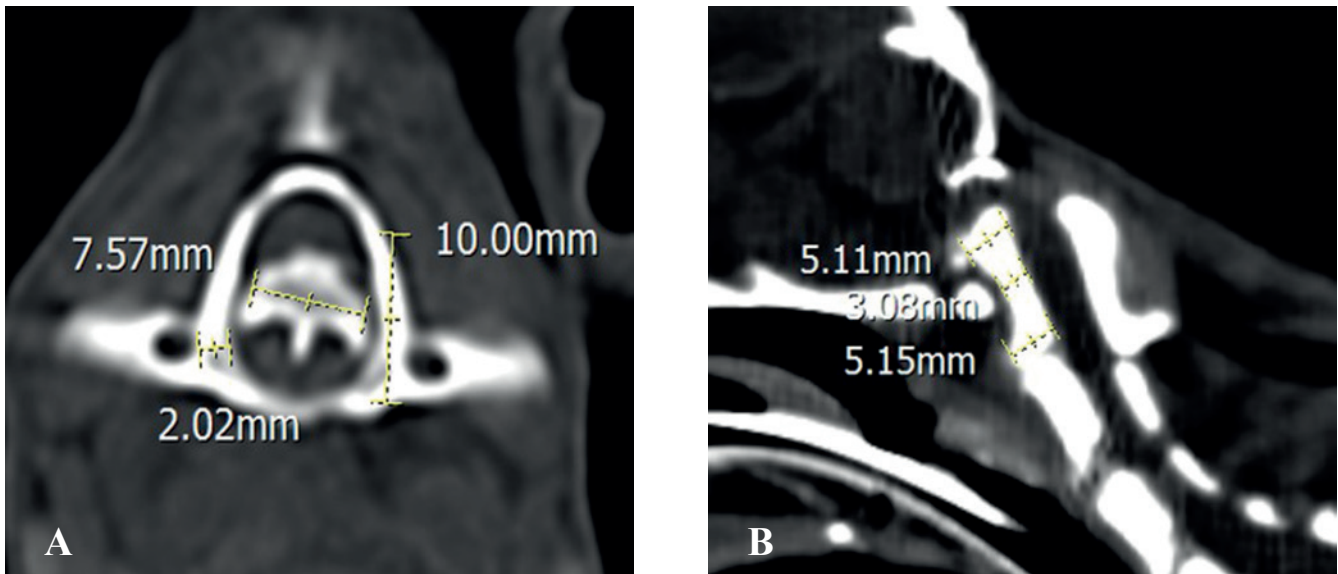
A one-year-old Yorkshire terrier of 1.2 kg was presented with an eight-month history of non-ambulatory tetraparesis. At the onset of clinical signs, the dog



**Figure 1.** Preoperative cervical radiographs. **A.** On the lateral view, the axis is displaced dorsally with respect to the atlas, and the lamina of atlas (white solid line) is not parallel with the lamina of axis (white dashed line). The body length of the atlas is shortened (white arrow) and malformation of the spinous process of axis is identified (black arrow). **B.** On the ventrodorsal view, lateral curvature of the craniocervical vertebrae is detected (white arrowheads), and an opacity of the dens is not clearly identified.



**Figure 2.** **A.** Three dimensional computed tomography reconstruction from the mid-sagittal view. The malformed axis is dorsally displaced and embedded into the vertebral canal of the atlas. Dens hypoplasia with a small bony fragment (black arrow) is found. Occipital dysplasia and atlanto-occipital overlapping are detected. The dorsal lamina of the atlas is invaginated into the intracranial region through the occipital bony defect (yellow arrowhead). **B.** Magnetic resonance imaging from the mid-sagittal view. The spinal cord is severely compressed at the atlantoaxial region (arrow) and the caudal cerebellar indentation (arrowhead) are observed.



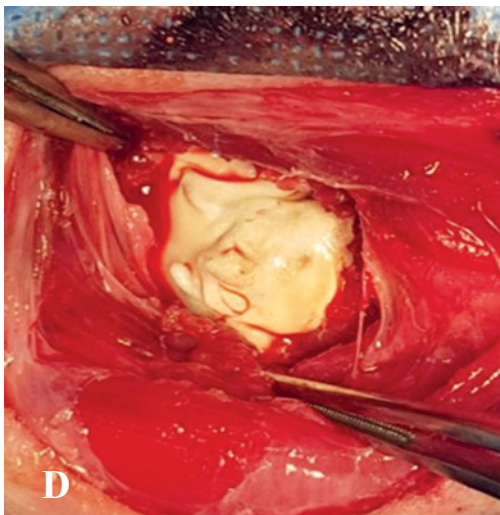
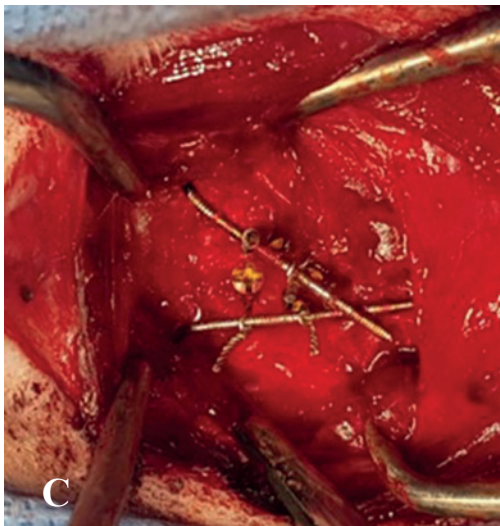
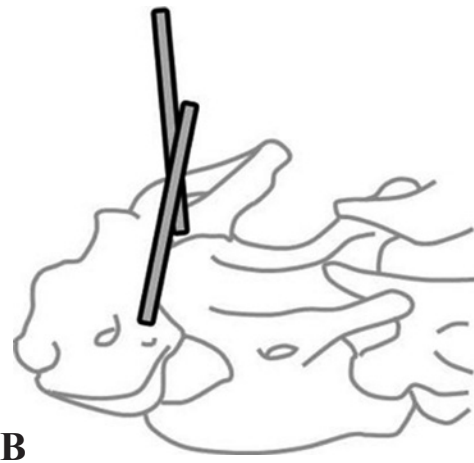
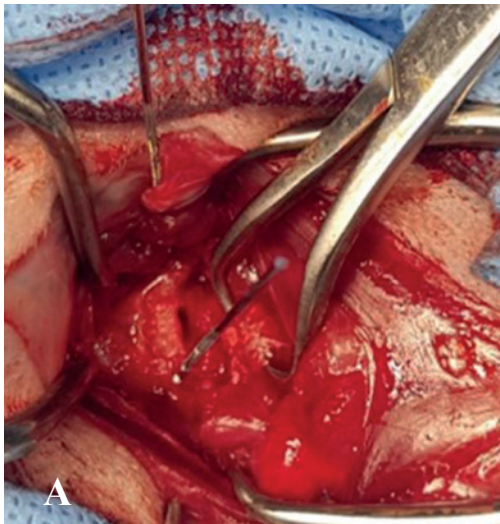
**Figure 3.** On CT imaging, the lengths are measured at several points on the atlas (C1) and axis (C2). A. Axial view of C1 just cranial to the atlantoaxial joint. The width of the C1 lateral mass is 2 mm. The length through the lateral mass at the medial side of the transverse foramen is 10 mm. The width of the cranial C2 body is 7.6 mm. B. Mid-sagittal view of the craniocervical region. The heights of the most cranial, middle, and most caudal parts of the C2 body are 5.1 mm, 3.1 mm and 5.2 mm, respectively.

was diagnosed with AAI by the referring veterinarian. The dog had been treated conservatively, including corticosteroid treatment and a neck splint during eight months, but had shown no response. On physical examination, the dog was very thin (body condition score 1/9) with severe muscle atrophy on all four limbs. The dog had mostly been laterally recumbent, and could not sit upright or eat on its own. Neurologic examination revealed non-ambulatory tetraparesis with intact pain perception. Survey radiographs revealed AAI, showing a shortened atlas (C1), dorsally displaced C2 body, malformation of the C2 spinous process, and suspected dens hypoplasia (Figure 1). To clarify the craniocervical region and plan the surgical procedure, computed tomography (CT) (BrightSpeed Elite Select, GE Healthcare, Beijing, China) and magnetic resonance imaging (MRI) (Magnetom Essenza 1.5-T magnet, Siemens, Erlangen, Germany) of the brain and cervical region were performed under general anesthesia induced by propofol (6 mg/kg, intravenously (IV)) and maintained with isoflurane and oxygen via tracheal intubation. According to the CT and MRI findings, the malformed C2 with dens hypoplasia was dorsally displaced and embedded into the C1 vertebral canal, causing severe spinal cord compression in the atlantoaxial region (Figure 2A). Other craniocervical junction abnormalities, including atlanto-occipital overlapping and occipital dysplasia, causing indentation of the caudal cerebellum, were detected concurrently (Figure 2B).

### Surgical planning

Based on a consultation with the owner, it was decided to perform surgery for AAI, and monitor the

progression of craniocervical junction abnormalities postoperatively. The surgical plan was ventral stabilization using multiple implant fixation (MIF), with implant placement for six corridors that have been evaluated as safe corridors in previous studies (Jeffery et al., 1996; Sanders et al., 2004; Vizcaino Revés et al., 2013). First of all, the bilateral C1 pedicular corridors: the insertion point is located from medial and caudal to the transverse foramen and just cranial to the AAJ, passing through the lateral mass of C1 to the dorsal lamina (Sanders et al., 2004; Leblond et al., 2016). Secondly, the bilateral C2 cranial articular surface corridors: the insertion point is located from the middle of the caudal aspect of the cranial articular surfaces of C2 on each side of midline, and directed dorsocraniolaterally with an insertion angle of approximately 30° laterally from the midline in a dorsal plane and 20° dorsally from the ventral line of the C2 body in a sagittal plane, toward the center of each C2 cranial articular surface (Sanders et al., 2004; Leblond et al., 2016). Lastly, the bilateral C2 caudal pedicular corridors: the insertion point is located from the base of the C2 transverse process, being directed laterally at 30° from the midline, through the C2 pedicle (Sanders et al., 2004; Leblond et al., 2016). To select the appropriate size of implants, the lengths of several points of C1 and C2 were measured on CT imaging. In the axial plane of C1 just cranial to the AAJ, the width of the lateral mass and the length from the C1 ventral surface to the dorsal lamina through the lateral mass were measured at 2 mm and 10 mm, respectively, and the width of the cranial C2 body was 7.6 mm (Figure 3A). In the mid-sagittal plane of C2, the heights of the most cranial and caudal sections and middle of the C2 body were 5.1 mm, 5.2 mm and 3.1



**Figure 4.** Surgical procedure of the tie-in configuration. A. and B. Two 0.9-mm-, positive-profile-threaded pins were inserted into the atlas (C1) pedicular corridors, medial and caudal to the transverse foramen and through the lateral mass bilaterally. C. and D. The pins engaging C1 were bent and secured with cerclage wire to the screws that engaged the axis. E. and F. Polymethylmethacrylate was molded over the triangular frame of the implants.

mm, respectively (Figure 3B). Based on these measurements, two 0.9-mm-, positive-profile-threaded pins were prepared for the C1 pedicular corridors and four 1.2-mm, self-tapping locking screws for the C2 corridors.

### Surgical technique

The dog was premedicated with cefazolin (20 mg/kg IV), butorphanol (0.2 mg/kg IV), famotidine (0.5 mg/kg IV), and midazolam (3 mg/kg IV). In addition, methylprednisolone sodium succinate (15 mg/kg IV) was administered as a free oxygen radical scavenger to protect the spinal cord from perioperative cord shift and reperfusion injury. Anesthesia was induced with propofol (4 mg/kg IV) and maintained with isoflurane (2%) in oxygen, following endotracheal intubation. The dog was positioned in dorsal recumbency with cranial traction of mandible and caudal traction of the thoracic limbs. A towel was placed between the surgical table and the neck to elevate and slightly extend the cranial cervical spine, being careful not to severely extend the spine causing neurological deterioration. After aseptic preparation, a ventral surgical routine approach was performed, as described in a previous report (Sanders et al., 2004). When the AAJ was exposed, the ventral side of C1 and caudal one third of C2 revealed that C2 was severely displaced cranio-dorsally and embedded into the C1 vertebral canal. The displaced C2 was reduced by pulling the third cervical vertebra caudo-ventrally, using a towel clamp to grasp the C3 ventral process. The thickened joint capsule was excised with a No. 11 scalpel blade and the articular cartilage of the AAJ was removed with the blade and a Cobb spinal curette with a straight cup. After opening the joint space, dens hypoplasia was identified, and the normal alignment of C1-C2 was achieved by aligning the caudal border of C1 and cranial border of C2 on the ventral side. Two 0.9-mm (0.9-mm shaft diameter, 1.1-mm thread diameter, 12 mm thread length, and 75 mm total length) positive-profile threaded pins (Miniature Stick Pins, IMEX Veterinary Inc, Longview, Tx) were inserted into the C1 pedicular corridors bilaterally (Figures 4A and 4B). After predrilling with a 0.7 mm- drill bit depth gauge, two 8.5 mm x 1.2 mm and two 6.5 mm x 1.2 mm, self-tapping locking screws (1.2 mini locking plate system, iMEDICOM, Gunpo, Republic of Korea) were placed into the bilateral C2 cranial articular surface corridors and the bilateral C2 caudal pedicular corridors, respectively. The screw head and a short segment of the treaded portion were exposed in all screws. The reduction was maintained while the pins were bent to bridge the distance between the screws, then the pins were secured to the screw heads on each side with 22-gauge cerclage wire (Figures 4C and 4D). When bending the pin, the base of the pin was hold firmly with a wire-twisting forceps and the rest of the pin was bent with a Kirschner wire bender under extreme caution not to cause excessive force

to the bone, which could result in iatrogenic damage of C1 or premature loosening of the pin. After the placement of all implants, 1 mg of bone morphogenetic protein (COWELL BMP Bone Graft, Cowellmedi Co., Ltd, Seoul, Korea) was applied to the AAJ. PMMA (Exolent spine, Elmdown, Ltd., London, UK) was then applied sufficiently to cover the entire frame and was copiously lavaged with saline (Figures 4E and 4F). The surgical site was closed routinely using 3-0 polydioxanone (PDS Plus; Ethicon, Somerville, New Jersey, USA) for muscular and subcutis closure and 3-0 polyamide (Dafilon; B. Braun, Barcelona, Spain) for skin closure.

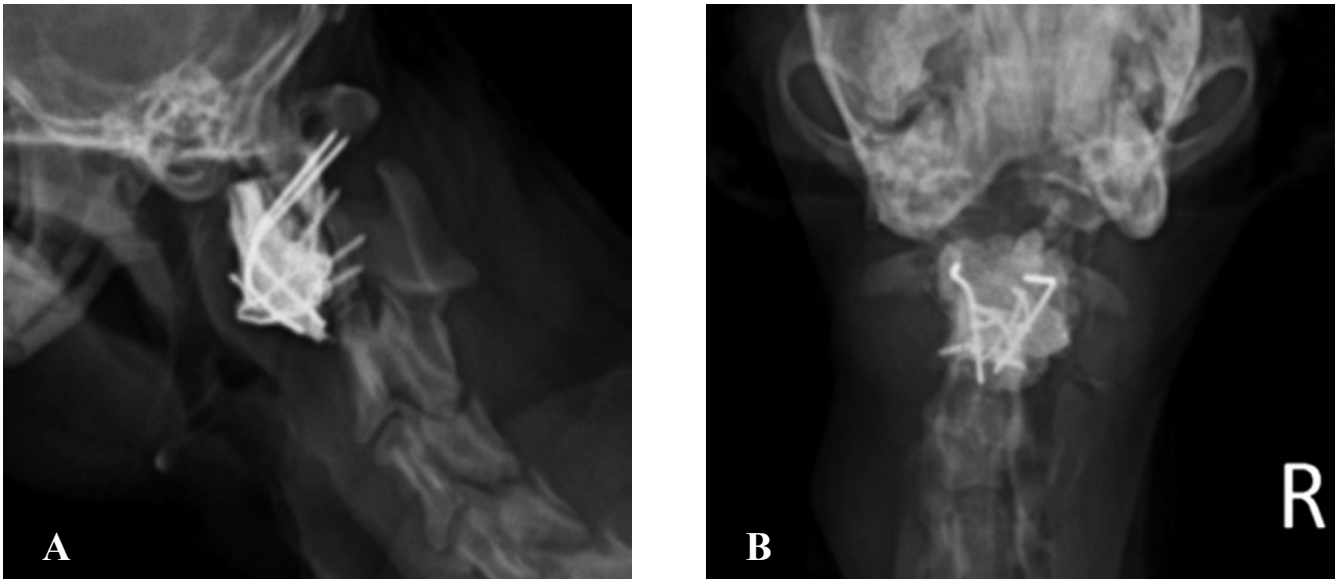
### Postoperative outcome

Lateral and ventrodorsal postoperative radiographs confirmed the adequate C2 reduction and normal C1-C2 alignment via ventral stabilization with the tie-in configuration (Figure 5). As postoperative analgesia, a continuous rate infusion of fentanyl (0.004 mg/kg/h) and lidocaine (1.2 mg/kg/h) was administered for 24 hours after surgery; subsequently, oral carprofen (2.2 mg/kg) and tramadol (4 mg/kg) twice daily for seven days were administered. A cervical soft bandage was applied for seven days postoperatively.

After surgery, the neurologic status of the dog improved rapidly. One day after surgery, the dog was able to sit upright and drink water and eat food by himself. In addition, he could stand without assistance for more than thirty seconds. After three days following the surgery, he was able to walk on his own and showed normal gait after seven days, despite mild weakness of the limbs due to the severe muscle atrophy. Based on eight months of follow-up, the dog was doing very well and had a completely normal gait.

### DISCUSSION

Of the various techniques for ventral stabilizations, MIF is one of the most recommended techniques. It has been shown to provide the greatest stability for AAJ in a mechanical strength test, and has demonstrated the highest fixation strength in the flexural test in a previous canine cadaveric study (Takahashi et al., 2017). Next to the biomechanics, MIF has additional advantages, including decreasing the risk of implant failure and related complications, and being specifically modifiable for each malformed vertebra (Platt et al., 2004; Sanders et al., 2004; Sharp and Wheeler, 2005; Dickomeit et al., 2011; Aikawa et al., 2013). However, similar to other ventral stabilizations, MIF is technically challenging for a toy breed dog (Leblond et al., 2016; Slanina, 2016). In this case report, it was decided to use a MIF, considering the extremely narrow bone corridors. To reduce the risk of perioperative complications related to the implant and to select the appropriate size of implants, preoperative measurements relating to the corridors were



**Figure 5. A. Postoperative lateral and B. ventrodorsal radiographs. The atlantoaxial joint is successfully stabilized with the tie-in configuration showing good reduction and normal alignment of the atlas (C1) and axis (C2). The pins that engage C1 are bent and secured with cerclage wire to the screws that engage C2. Polymethylmethacrylate covers the entire frame.**

performed using CT. Based on these measurements, 0.9-mm-, positive-profile-threaded pins were selected for the C1 pedicular corridors. Originally, the authors tried to use screws for all the corridors because the screws provide better holding power and have a lower possibility of migration compared to smooth pins (Platt et al., 2004). However, the C1 pedicular corridor was too narrow and long to accommodate the traditional screw sizes used for AAI stabilization in a toy breed dog. In particular, the screw with a 1.5-mm diameter was too big for the 2-mm width bone corridor, and smaller-diameter screws (1.1 or 1.2 mm) that have a commercially available length of only 8.5 mm, were not long enough to engage the whole path, including the near and far cortex of the corridor. Consequently, the use of a proper sized, positive-profile-threaded pins produced a successful outcome. It reduced the risk of iatrogenic damage of the vertebra and spinal cord, and provided sufficient vertebral holding power that was less likely to migrate due to its sufficient length and thread.

Additionally, the pins engaging C1 were concurrently used as a connecting bar for bridging the distance between the screws engaging C2. This tie-in frame configuration is similar to that of the tie-in technique of external skeletal fixation. The pins, screws and cerclage wires in this study correspond to the intramedullary pin and connecting bar, fixation half-pin, and the linkage device in external skeletal fixation, respectively. This configuration has additional advantages over other MIFs providing more stability. Because the connecting bar was the same pin engaging C1, it was not necessary to secure an independent connecting bar to the implant that engaged C1 and to make it fit around a screw head. This structural fea-

ture was considered to make the frame more simple and rigid by decreasing the linkage area. Moreover, this configuration could have the additional benefit of preventing pin migration. Since the pin engaging C1 was secured to the screws engaging C2 directly, it was possible to avoid independent pin movement, which prevented the pin from migrating both dorsally or ventrally. Further, the bent structure could also prevent dorsal migration of the pin by blocking the dorsal displacement.

This configuration may also reduce complications related to the PMMA. The volume of PMMA typically required for this type of surgery is associated with fatal complications, especially in very small dogs, because its considerable volume can cause thermal or pressure necrosis to the adjacent structures (Aikawa et al., 2013). In the present configuration, the ends of two pins were concentrated at one point, making a triangular frame that minimizes the volume of PMMA needed, compared with a square frame that places two pins in parallel.

The main limitation of this study is that this novel technique has been applied to only one case, hence, future research is needed to further evaluate the effectiveness and safety of this configuration for very small dogs with AAI. This is particularly true because MIF must function under a diversity of maximum loads and fixation strengths among patients due to the variability of the frame caused by inconsistent positioning and angles of implant insertion, which also affect the required PMMA volume (Takahashi et al., 2017). Therefore, more data should be collected to ensure the consistency of this configuration for stabilization of AAI.

This frame of MIF, i.e. a tie-in configuration us-

ing positive-profile-threaded pins, screws, wires and PMMA, led to an excellent clinical outcome in a toy breed dog with congenital AAI. The structural advantages of this configuration and the use of appropriately sized implants based on preoperative measurements produced good results in a small sized dog, in which the surgical stabilization of AAI is typically challenging. Studies with larger populations are required to further define the value and the outcome of this technique.

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