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CASE REPORT

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Outcomes of 87 small-breed dogs surgically treated for Chiari-like malformation and syringomyelia

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Abstract

Objective: To report the outcomes of titanium mesh (TM) cranioplasty without polymethylmethacrylate (PMMA), incorporating a deliberate gap between the foramen magnum decompression (FMD) surface and the TM, in small-breed dogs with Chiari-like malformation and syringomyelia (CM/SM).

Study design: Retrospective clinical study.

Animals: A total of 87 client-owned small-breed dogs diagnosed with CM/SM by magnetic resonance imaging, all presenting with neurologic deficits.

Methods: All dogs underwent modified FMD. A gap was preserved between the FMD surface and the TM to facilitate tissue integration and reduce postoperative compressive forces. Clinical status was assessed based on neurologic improvement, medication dependency, and need for revision surgery.

Results: Surgical decompression with the modified TM technique resulted in sustained clinical improvement in most dogs. A total of 76 dogs (87%, 76/87) showed long-term improvement, and no revision surgeries were required during a median follow-up of 35 months (range: 27–73 months). Follow-up evaluation comprised postoperative computed tomography (CT) imaging at 6 months, as well as structured telephone interviews with owners to monitor clinical status. Only a small subset of dogs (13%, 11/87) required continued medication after surgery due to recurrence of signs.

Conclusion: Retrospective analysis showed that the modified TM technique, using a deliberate gap, was safe and effective in small-breed dogs with CM/SM, successfully preserving the decompression space and maintaining long-term neurologic stability.

Clinical relevance: The modified TM technique approach achieves durable neurologic improvement and minimizes long-term complications in small-breed dogs, demonstrating practical utility in managing this clinically challenging population.

1 | INTRODUCTION

Chiari-like malformation (CM) affects not only humans but also dogs.[1] Certain breeds, particularly Cavalier King Charles Spaniels, are predisposed to a condition similar to human Chiari type I malformation.[1–4] In CM, the cerebellar tonsils and occasionally a portion of the medulla oblongata are elongated and displaced caudally through the foramen magnum into the cranial cervical spinal canal. This displacement compresses the spinal cord and causes kinking, as the medulla and fourth ventricle are pushed caudally. Syringomyelia (SM) is associated with CM/SM and may develop secondarily due to congestion of the foramen magnum and obstruction of cerebrospinal fluid (CSF) flow.[1–10]

Clinical signs may include cervical pain, torticollis, exercise intolerance, spinal hyperesthesia, paresis of one or both thoracic limbs, tetraparesis, thoracic limb ataxia or hypermetria, proprioceptive ataxia, poor proprioceptive positioning, and decreased hopping responses. Although no dermatologic lesions are present, phantom scratching is commonly triggered by excitement, exertion, barking, wearing a collar, or physical contact with the neck, ear, or shoulder on the affected side. This conspicuous behavior may be due to disinhibition of pelvic limb reflex activity or secondary paresthesia caused by syringomyelia, potentially resulting from disruption of the decussating spinothalamic tracts and damage to the dorsal and ventral horns from a progressively expanding syrinx.[11–13] Diagnosis of CM and SM is primarily based on magnetic resonance imaging (MRI) of the head and cervical vertebral column.

In human patients with CM, foramen magnum decompression (FMD) is the standard surgical treatment.[14,15] However, 8%–30% of patients may require reoperation due to excessive postoperative scar tissue, which can cause renewed compression at the foramen magnum.[16–18] Similarly, in the veterinary literature, while some reports show a small percentage or no reoperations, some reports have an up to 25% reoperation rate following FMD.[3,4,19] To reduce postoperative scar tissue formation and prevent recompression, reconstruction of the caudal occipital region using autologous bone grafts has been described in humans, with evidence suggesting a reduced incidence of scar formation.[20,21] Conversely, placement of absorbable gelatin sponge material (Gelfoam) over the meningeal defect is associated with increased scar formation in human Chiari type I patients, highlighting the importance of graft material selection at the FMD site.[3,15,20,21]

Previous studies have reported that postoperative symptom deterioration in CM/SM cases has been observed at a minimum of 3 to 7 months after FMD surgery.[4,19] Cranioplasty using titanium mesh (TM) or polymethylmethacrylate (PMMA) shows promise in both human and canine cases of CM and CM/SM by preventing compression caused by postoperative scar tissue formation.[4] However, in small-breed dogs, the use of TM and PMMA is challenging due to the limited size of the occipital region. Therefore, this study aimed to assess the clinical utility and outcomes of modified TM technique without PMMA in 87 small-breed dogs with CM/SM, with a focus on minimizing postoperative complications and surgical recurrence.

2 | MATERIALS AND METHODS

2.1 | Case selection

This retrospective study included 87 client-owned small-breed dogs diagnosed with CM/SM based on MRI findings and associated clinical signs. All dogs underwent FMD followed by cranioplasty using a TM at IU Animal Medical Center between 2016 and 2021. Although early complications often manifest within the first 3 months, a minimum follow-up of 27 months was chosen to confirm the long-term sustainability of the surgical outcome.[4] Collected data included breed, age, sex, bodyweight, clinical signs, duration of signs prior to surgery, CM and SM grades on MRI, postoperative medical treatment, clinical outcomes and follow-up duration. Postoperative clinical improvement was assessed based on the resolution or reduction of preoperative clinical signs, including phantom scratching, pain, and proprioceptive ataxia.

Clinical improvement was defined as the resolution or owner-reported subjective marked reduction (≥50%) of the severity or frequency of preoperative clinical signs—such as phantom scratching, pain, or ataxia—with improvement in any one of these primary signs being sufficient for classification, sustained for at least 6 months without continuous pharmacologic support. The 50% threshold was based on a structured questionnaire administered to the owners during follow-up.

Preoperative assessment of CM and SM was performed using MRI images (Figure 1), adopting a semi-quantitative grading approach based on the system proposed by Cerda-Gonzalez et al.[13] Postoperative three-dimensional computed tomography (3D-CT) and radiographs were obtained to confirm proper implant placement (Figure 2), and all 87 dogs (100%) underwent a 6-month postoperative CT to evaluate the surgical site and implant positioning (Figure 3). Owners were advised to return annually for CT evaluation after first 6- month recheck; however, when in-person visits were not feasible, follow-up was conducted via telephone to monitor clinical status. In practice, most owners complied with the 6-month postoperative CT, while subsequent follow-up was primarily conducted by phone, particularly when dogs

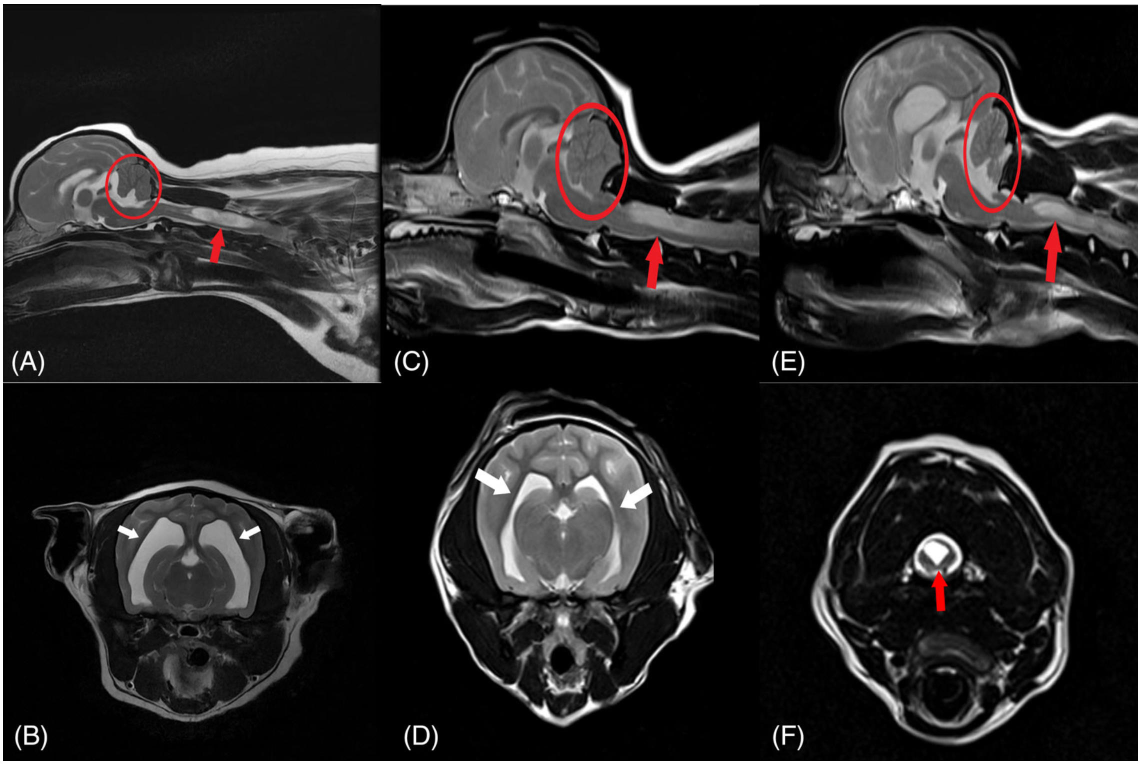

FIGURE 1 Representative magnetic resonance imaging (MRI) features in dogs with Chiari-like malformation and syringomyelia (CM/SM). (A, B) Transverse T2-weighted images from a dog diagnosed with CM grade 1 and SM grade 2, demonstrating marked dilation of the lateral ventricles (ventriculomegaly). (C, D) Transverse T2-weighted images from a dog with CM grade 2 and SM grade 2, showing only mild ventricular dilation. (E, F) Transverse and sagittal T2-weighted images at the level of the cervical spinal cord in a dog with CM grade 2 and SM grade 2, revealing a prominent syrinx with severe dilation of the central canal, indicating advanced SM. * Red circles indicate regions assessed for CM grading, Red arrows indicate regions assessed for SM grading, White arrows indicate areas of lateral ventriculomegaly.

showed clinical improvement and remained stable. The overall follow-up period had a median of 35 months and ranged from 27 to 73 months.

2.2 | Anesthesia protocol

All dogs were premedicated with tramadol (2–4 mg/kg IV) and meloxicam (0.2 mg/kg subcutaneously). General anesthesia was induced and maintained with sevoflurane in oxygen. To reduce intracranial pressure, mannitol (0.5 g/kg IV) was administered over 10–15 min prior to surgery. Cefazolin (22 mg/kg IV) was administered at the induction of anesthesia and repeated following the surgical procedure.

2.3 | Surgical procedure

All surgeries were performed by the lead author (SSP). The FMD procedure was carried out as previously described,[4,22] with the exception that neither a gelatin sponge nor a dural substitute was applied. Following decompression, 2–4 guide holes were drilled around the periphery of the foramen magnum using a 1.1 mm drill bit to accommodate 1.5 mm cortical titanium screws. These screws (4 mm length, 2–3 mm depth) served as anchor posts for the titanium mesh. The implant used was a veterinary titanium mesh plate 1 T (Jeil Medical, Seoul, Korea). To maintain the decompression gap and prevent postoperative deformation, the TM was manually contoured to follow the natural curvature of the occipital bone, replicating the shape of the original caudal skull. This curvature evenly distributed mechanical stress across the TM and minimized the risk of gradual bending or “bounce” once the animal resumed normal head and neck movement. During surgery, the optimal mesh length and curvature were determined by manually checking cervical flexion and extension, ensuring a 5–6 mm clearance from the dorsal aspect of the first cervical vertebra.

The mesh was fixed to the thickest cortical areas of the occipital bone, identified on preoperative CT cross-sections, using 1.5-mm cortical screws (4 mm length, 2–3 mm insertion depth). This rigid fixation provided

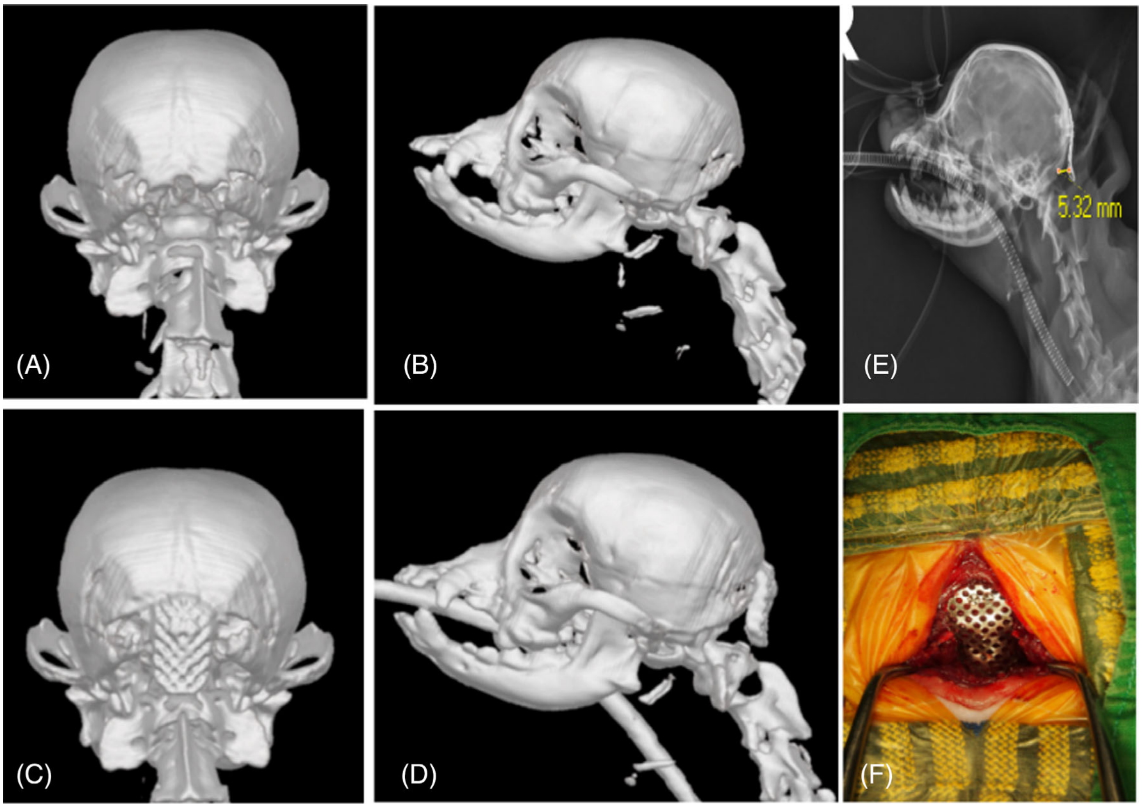

FIGURE 2 Pre-, intra-, and postoperative imaging and intraoperative evaluation of cranioplasty for foramen magnum decompression (FMD). (A, B) Preoperative three-dimensional-computed tomography (3D-CT) reconstructions used to assess occipital bone morphology and plan the surgical approach for cranioplasty. (C, D) Postoperative 3D-CT reconstructions obtained immediately after surgery, demonstrating correct positioning and fixation of the titanium mesh (TM) implants. (E) Lateral skull radiograph taken postoperatively, the intentional gap between the titanium mesh and the FMD surface is visualized, with the spacing dimension explicitly indicated, confirming the presence and stability of the TM implant and the absence of postoperative complications. (F) Intraoperative photograph showing a contoured veterinary titanium mesh plate 1 T (Jeil Medical, Seoul, Korea) fixed to the occipital bone with 1.5-mm cortical screws (4 mm length). The mesh follows the occipital curvature, maintaining a 5–6 mm decompression gap over the cerebellar surface and avoiding contact with the dorsal arch of the first cervical vertebra.

stable anchorage and prevented displacement or lifting of the mesh edges. The overall configuration and fixation sites are shown in Figure 2.

For optimal implant positioning, the curvature and caudal extent of the titanium mesh were planned using 3D-CT reconstruction of the occipital region. During surgery, the mesh was positioned to cover the decompression defect symmetrically and extended just caudal to the foramen magnum without exceeding the dorsal lamina of the first cervical vertebra. This configuration prevented impingement on the medulla or dorsal cervical cord while preserving normal atlanto-occipital motion. Care was taken to avoid excessive caudal extension or sharp bending angles that could lead to postoperative tension or instability. These practical adjustments were derived from intraoperative assessment of neck flexion and extension to confirm an anatomically compatible fit.

Postoperative imaging was routinely performed as described in the Materials and Methods section (Figure 2).

2.4 | Postoperative management

Postoperative analgesia included a fentanyl patch (12.5 μg, dermal) applied for 72 h. Gabapentin (10 mg/kg orally every12 h) or pregabalin (5 mg/kg orally every 12 h) was administered for 7 days. Cephalexin (22 mg/kg orally every 12 h) was also given for 7 days. Dogs were discharged 3 to 7 days after surgery with instructions for strict confinement for 10 days, followed by gradual return to normal activity over 3 to 10 days. Re-evaluations were performed at 6 months post-discharge and as needed thereafter.

2.5 | Statistical analysis

Statistical evaluation was limited to descriptive analyses. Normality of continuous variables, including age, bodyweight, and postoperative follow-up duration, was assessed

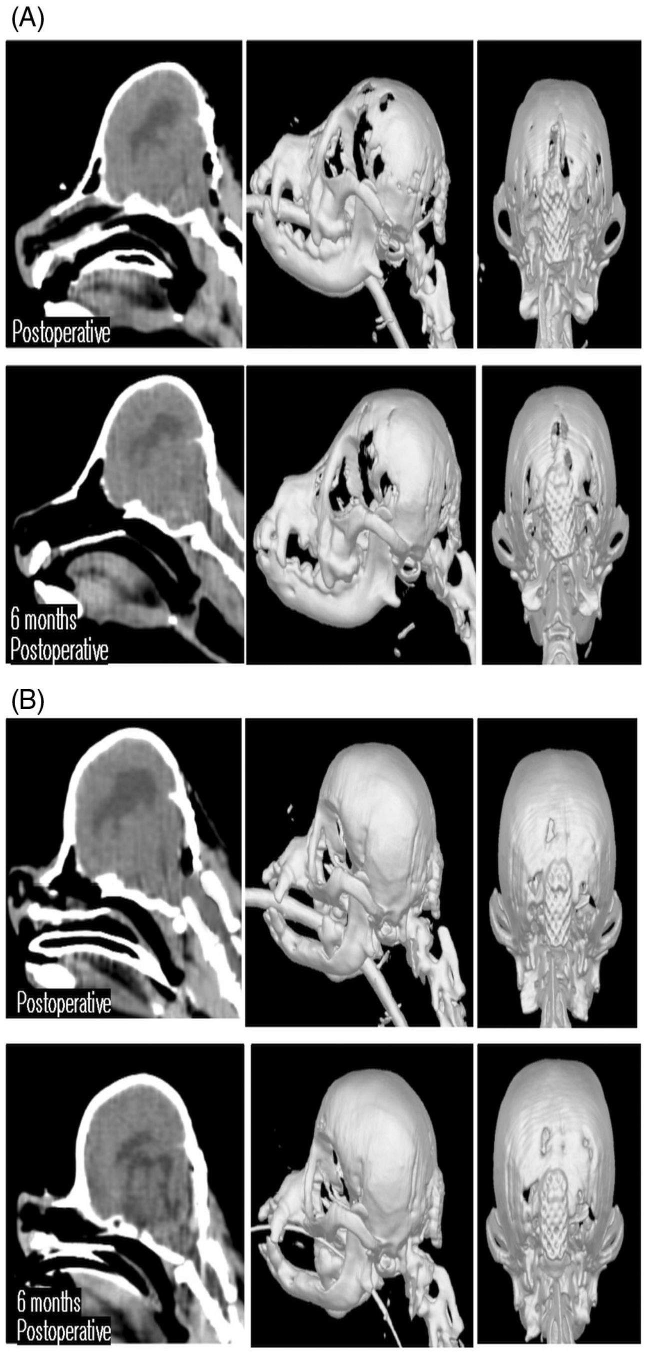

FIGURE 3 Postoperative computed tomography (CT) images of the foramen magnum decompression (FMD) site in small-breed dogs. (A) A dolichocephalic small-breed dog. The soft-tissue window images confirm a deliberate gap immediately postoperative (top panel) and its sustained presence 6 months postoperative (bottom panel), with no evidence of cerebellar compression. (B) A brachycephalic small-breed dog. The soft-tissue window images demonstrate the maintenance of the deliberate gap both immediately postoperative (top panel) and at the 6-month postoperative follow-up (bottom panel). A corresponding three-dimensional (3D) bone-rendered computed tomography (CT) view has been incorporated to delineate the titanium mesh and surrounding bone, clearly illustrating the extent of cranioplasty over the foramen magnum defect.

using the Shapiro–Wilk test. Because these variables were not normally distributed, results are expressed as medians with ranges. Categorical variables, such as the presence of clinical signs, postoperative improvement, and reoperation rate, are presented as both percentages and absolute ratios (n/N). All analyses were performed using standard spreadsheet software.

3 | RESULTS

3.1 | Signalment and clinical findings

At the time of surgery, the median age was 4 years (range: 5 months to 11 years) and the median bodyweight was 2.9 kg (range: 1.1–4.8 kg). The study population included 38 neutered males, 31 spayed females, 10 intact females, and eight intact males. Breeds included 32 Maltese, 28 Pomeranians, eight Yorkshire Terriers, nine Chihuahuas, nine Poodles, and one Bichon Frise. Presenting clinical signs included phantom scratching ($n = 58$), pain ($n = 40$), and proprioceptive ataxia ($n = 18$). The median duration of clinical signs prior to surgery was 4 months (range: 1 day to 5 years) (Table 1).

3.2 | Preoperative findings

The severity of CM and SM was assessed via MRI in all 87 dogs. Representative transverse T2-weighted MRI images are shown in Figure 1. A dog with CM grade 1 and SM grade 2 exhibited marked dilation of the lateral ventricles (Figure 1A,B), whereas another dog with CM grade 2 and SM grade 2 showed only mild ventricular dilation (Figure 1C,D). Additionally, a dog with CM grade 2 and SM grade 2 presented with severe dilation of the cervical spinal cord's central canal, indicating advanced SM progression (Figure 1E,F). These findings suggest that CM severity does not necessarily correlate with the degree of lateral ventricular or central canal dilatation.

3.3 | Perioperative management

All dogs underwent the modified TM technique, and the procedure was completed without intraoperative complications. Immediate postoperative CT and radiography were performed while the dogs were under general anesthesia to confirm implant positioning and to check for acute complications. The CT scans were considered sufficient to confirm proper placement of the TM and to rule out any acute complications, despite minor metal artifacts. A lateral radiograph obtained prior to extubation

TABLE 1 Summary of clinical outcomes in 87 small breed dogs undergoing FMD with TM based cranioplasty for treatment of CM/SM.

Dog	Signalment	Clinical sign	Duration before surgery	CM grade	SM grade	Postoperative drugs	Postoperative complication	Outcome	Follow-up
1	6 year, 2.3 kg, Poodle, MN	Phantom scratching, mild forelimb pain on palpation	35 days	1	1	None	No	Improved	48 m
3	10 year, 2 kg, Maltese, FS	Neck pain, proprioceptive ataxia	1 m	2	2	None	No	Improved	49 m
4	3 year, 2.1 kg, Yorkshire Terrier, MN	Phantom scratching	15 days	2	0	None	No	Improved	49 m
5	5 year, 1.5 kg, Maltese, MN	Severe head/neck pain	1 days	2	2	None	No	Improved	47 m
6	5 year, 2.2 kg, Pomeranian, FS	Severe head/neck pain, phantom scratching	3 m	2	2	None	No	Improved	57 m
7	6 year, 3.5 kg, Maltese, MN	Seizure, severe neck/forelimb pain, phantom scratching	1 year	2	2	Gabapentin, pregabalin	No	Not Improved	73 m
8	7 year, 3.1 kg, Chihuahua, FS	Seizure, mild neck pain	2 year	2	1	Gabapentin, pregabalin	No	Not Improved	55 m
9	1 year, 2.9 kg, Pomeranian, MN	Proprioceptive ataxia, neurologic pain/ hyperesthesia	5 m	2	2	None	No	Improved	52 m
11	8 year, 2.1 kg, Yorkshire Terrier, MN	Phantom scratching, neurologic pain/ hyperesthesia	5 year	2	2	Gabapentin, pregabalin	No	Not Improved	46 m
12	8 year, 4.2 kg, Pomeranian, FS	Severe neck/forelimb pain, phantom scratching, hyperesthesia	8 m	2	2	None	No	Improved	45 m \
13	5 year, 2.8 kg, Maltese, FS	Severe neck/forelimb pain, phantom scratching, hyperesthesia	2 year	2	2	Gabapentin, pregabalin	No	Improved	48 m
14	4 year, 1.7 kg, Chihuahua. MN	Stiffness, phantom scratching, hyperesthesia	1 year	2	2	None	No	Improved	46 m
15	1 year, 2.6 kg, Pomeranian, F	Stiffness, phantom scratching	7 days	1	1	None	No	Improved	44 m
16	6 year, 2.6 kg, Maltese, FS	Proprioceptive ataxia, neurologic pain/ hyperesthesia	6 m	1	3	None	No	Improved	44 m
17	8 month, 3 kg, Bichon Frise, FS	Stiffness, phantom scratching, scoliosis	1 m	2	3	None	No	Improved	43 m
18	3y. 1.9 kg, Yorkshire Terrier, MN	Lt. head tilt, proprioceptive ataxia, circling	1 m	2	1	Gabapentin, pregabalin	No	Improved	44 m
19	4 year, 1.9 kg, Yorkshire Terrier, F	Stiffness, neurologic pain/hyperesthesia	14 days	1	2	None	No	Improved	43 m

TABLE 1 (Continued)

Dog	Signalment	Clinical sign	Duration before surgery	CM grade	SM grade	Postoperative drugs	Postoperative complication	Outcome	Follow-up
20	7 year, 3.8 kg, Maltese, MN	Proprioceptive ataxia, phantom scratching, stiffness	1 m	1	2	Gabapentin, pregabalin	No	Improved	44 m
21	9 year, 2.1 kg, Maltese, MN	Phantom scratching, neurologic pain/hyperesthesia, facial paralysis	1 year	2	2	None	No	Improved	44 m
22	7 year, 2.7 kg, Yorkshire Terrier, MN	Phantom scratching, stiffness, proprioceptive ataxia	3 year	2	2	Gabapentin, pregabalin	No	Not Improved	43 m
23	4 year, 4.7 kg, Maltese, MN	Stiffness	1 year	1	1	None	No	Improved	48 m
24	3 year, 2.5 kg, Maltese, FS	Stiffness	7 m	1	2	Gabapentin, pregabalin	No	Improved	46 m
25	1 year, 1.5 kg, Maltese, M	Stiffness	14 days	1	2	None	No	Improved	45 m
26	6 year, 4.8 kg, Pomeranian, MN	Severe neck pain, hyperesthesia	5 m	1	2	Gabapentin, pregabalin	No	Improved	48 m
27	1 year, 2.1 kg, Pomeranian, MN	Severe neck pain, hyperesthesia	14 days	1	2	Gabapentin, pregabalin	No	Improved	40 m
28	1 year, 1.8 kg, Maltese, MN	Seizure, stiffness	1 m	2	1	Gabapentin, pregabalin	No	Improved	42 m
29	1 year, 2.4 kg, Pomeranian, MN	Stiffness	1 m	2	2	None	No	Improved	40 m
30	3 year, 2.4 kg, Maltese, FS	Stiffness, neurologic pain/hyperesthesia	6 m	2	2	None	No	Improved	39 m
31	1 year, 1.9 kg, Pomeranian, FS	Stiffness, neurologic pain/hyperesthesia	6 days	1	1	None	No	Improved	39 m
32	3 year, 2 kg, Yorkshire Terrier, FS	Seizure, stiffness, neurologic pain/hyperesthesia	2 year	2	1	Gabapentin, pregabalin	No	Not Improved	39 m
33	5 year, 3.6 kg, Maltese, MN	Neurologic pain/hyperesthesia	5 year	1	2	None	No	Improved	38 m
34	5 month, 2.6 kg, Pomeranian, F	Head tilt, proprioceptive ataxia, circling	1 m	2	1	None	No	Improved	38 m
35	1 year, 2.4 kg, Chihuahua, MN	Neurologic pain/hyperesthesia	1 m	2	2	Gabapentin, pregabalin	No	Improved	38 m
36	5 year, 2.9 kg, Maltese, M	Seizure, stiffness, neurologic pain/hyperesthesia	3 year	1	1	None	No	Improved	38 m

(Continues)

TABLE 1 (Continued)

Dog	Signalment	Clinical sign	Duration before surgery	CM grade	SM grade	Postoperative drugs	Postoperative complication	Outcome	Follow-up
37	2 year, 2.5 kg, Chihuahua, FS	Neurologic pain/hyperesthesia	1 year	2	2	None	No	Improved	38 m
38	1 year, 2.3 kg, Pomeranian, F	Neurologic pain/hyperesthesia	2 m	1	2	None	No	Improved	38 m
39	8 year, 3.4 kg, Maltese, FS	Neurologic pain/hyperesthesia	3 days	2	2	None	No	Improved	37 m
40	3 year, 2.8 kg, Pomeranian, M	Dystrophic change, neurologic pain/ hyperesthesia	3 year	2	2	None	No	Improved	37 m
41	1 year, 1.9 kg, Pomeranian, MN	Phantom scratching, hyperesthesia	1 m	1	2	None	No	Improved	28 m
42	5 year, 1.9 kg, Maltese, FS	Phantom scratching, proprioceptive ataxia, tic	6 m	1	1	None	No	Improved	29 m
43	9 year, 1.3 kg, Maltese, F	Severe neck/forelimb pain	1 year	1	1	None	No	Improved	34 m
44	2 year, 3.2 kg, Pomeranian, M	Stiffness, proprioceptive ataxia	1 year	2	2	Gabapentin, pregabalin	No	Improved	33 m
45	7 year, 4.5 kg. Poodle, FS	Forelimb pain, hyperesthesia	8 m	2	2	Gabapentin, pregabalin	No	Improved	33 m
46	3 year, 1.1 kg, Pomeranian, F	Stiffness	1 m	1	2	None	No	Improved	33 m
47	8 year, 1.8 kg, Maltese, F	Stiffness, phantom scratching, hyperesthesia	1 m	1	1	None	No	Improved	32 m
48	3 year, 2.4 kg, Chihuahua, MN	Severe neck/forelimb pain, hyperesthesia	1 m	2	2	None	No	Improved	31 m
49	4 year, 3.6 kg, Poodle, FS	Stiffness. Phantom scratching, hyperesthesia	2 m	2	1	Gabapentin, pregabalin	No	Improved	30 m
50	3 year, 2.6 kg, Pomeranian, MN	Phantom scratching, hyperesthesia	6 m	1	1	None	No	Improved	30 m
51	4 year, 1.8 kg, Maltese, FS	Forelimb pain, hyperesthesia	3 m	2	1	None	No	Improved	36 m
52	3 year, 2.5 kg, Pomeranian, M	Stiffness	2 year	2	2	None	No	Improved	36 m
53	5 year, 2.9 kg, Pomeranian, MN	Severe neck/forelimb pain	8 m	1	1	None	No	Improved	35 m
54	6 year, 3.5 kg, Pomeranian, FS	Severe neck/forelimb pain	1 m	2	2	None	No	Improved	35 m

TABLE 1 (Continued)

Dog	Signalment	Clinical sign	Duration before surgery	CM grade	SM grade	Postoperative drugs	Postoperative complication	Outcome	Follow-up
55	1 year, 1.3 kg, Poodle, M	Phantom scratching, circling	1 m	2	2	Zonisamide	No	Improved	35 m
56	6 year, 2.2 kg, Maltese, FS	Phantom scratching, stiffness	4 year	1	2	Levetraicetam, gabapentin	No	Not Improved	34 m
57	1 year, 1.8 kg, Pomeranian, MN	Forelimb pain, hyperesthesia	1 m	2	1	None	No	Improved	34 m
58	5 year, 2.5 kg, Pomeranian, MN	Stiffness	4 year	2	1	Gabapentin, pregabalin	No	Improved	34 m
59	10 year, 3.5 kg, Yorkshire Terrier, FS	Stiffness	1 m	1	2	None	No	Improved	33 m
60	2 year, 1.2 kg, Maltese, F	Proprioceptive ataxia, Tic, hyperesthesia	8 m	2	1	None	No	Improved	33 m
61	1 year, 2.3 kg, Poodle, FS	Phantom scratching, hyperesthesia, proprioceptive ataxia	4 m	2	1	None	No	Improved	32 m
62	2 year, 1.8 kg, Poodle, FS	Hyperesthesia, stiffness	7 m	1	2	None	No	Improved	32 m
63	5 year, 2.4 kg, Chihuahua, FS	Stiffness, proprioceptive ataxia	1 year	1	2	Gabapentin	No	Improved	32 m
64	1 year, 2.5 kg, Pomeranian, MN	Neck pain, proprioceptive ataxia	4 m	2	1	Gabapentin, pregabalin	No	Improved	32 m
65	9 year, 3.4 kg, Maltese, FS	Severe neck/forelimb pain, hyperesthesia	1 year	1	1	Gabapentin, pregabalin	No	Improved	32 m
66	2 year, 2.4 kg, Chihuahua, MN	Severe neck/forelimb pain, scratching around head/neck	2 year	2	1	Gabapentin, pregabalin	No	Improved	32 m
67	6 year, 3.5 kg, Maltese, MN	Tic, forelimb pain	1 year	2	1	CBD oil	No	Improved	31 m
68	8 year, 2.9 kg, Maltese, MN	Stiffness, proprioceptive ataxia	3 year	2	1	None	No	Improved	31 m
69	1 year, 2.8 kg, Maltese, FS	Stiffness, tic	1 m	2	2	None	No	Improved	31 m
70	2 year, 3 kg, Pomeranian, F	Neck pain, proprioceptive ataxia	3 m	1	1	Gabapentin, pregabalin	No	Improved	30 m
71	1 year, 2.5 kg, Poodle, MN	Phantom scratching, hyperesthesia	5 m	2	1	Gabapentin, pregabalin	No	Improved	30 m
72	3 year, 2.2 kg, Maltese, MN	Stiffness, proprioceptive ataxia	1 m	1	2	Gabapentin, pregabalin	No	Improved	30 m

(Continues)

TABLE 1 (Continued)

Dog	Signalment	Clinical sign	Duration before surgery	CM grade	SM grade	Postoperative drugs	Postoperative complication	Outcome	Follow-up
73	1 year, 2.2 kg, Maltese, MN	Forelimb pain, hyperesthesia	1 year	1	2	Gabapentin, pregabalin	No	Improved	30 m
74	3 year, 2 kg, Maltese, FS	Phantom scratching, proprioceptive ataxia	1 m	2	2	Levetraicetam, zonisamide	No	Improved	30 m
75	4 year, 1.8 kg, Chihuahua, MN	Phantom scratching, stiffness	1 year	1	1	None	No	Improved	30 m
76	4 year, 2.4 kg, Chihuahua, MN	Severe neck/forelimb pain, hyperesthesia	2 m	2	1	None	No	Improved	29 m
77	5 year, 3.6 kg, Poodle, FS	Stiffness. Phantom scratching, hyperesthesia	3 m	1	1	Gabapentin, pregabalin	No	Improved	29 m
78	4 year, 2.6 kg, Pomeranian, MN	Phantom scratching, hyperesthesia	7 m	2	1	None	No	Improved	29 m
79	5 year, 1.8 kg, Maltese, FS	Forelimb pain, hyperesthesia	4 m	2	1	None	No	Improved	28 m
80	4 year, 2.5 kg, Pomeranian, M	Stiffness	3 year	1	2	None	No	Improved	28 m
81	6 year, 2.9 kg, Pomeranian, MN	Severe neck/forelimb pain	9 m	1	2	None	No	Improved	28 m
82	2 year, 1.3 kg, Poodle, M	Phantom scratching, circling	2 m	1	1	Zonisamide	No	Improved	28 m
83	7 year, 2.2 kg, Maltese, FS	Phantom scratching, stiffness	5 year	1	1	Levetraicetam, gabapentin	No	Not Improved	27 m
84	2 year, 1.8 kg, Pomeranian, MN	Forelimb pain, hyperesthesia	2 m	1	1	None	No	Improved	27 m
85	6 year, 2.5 kg, Pomeranian, MN	Stiffness	5 year	1	1	Gabapentin, pregabalin	No	Improved	27 m
86	11 year, 3.5 kg, Yorkshire Terrier, FS	Stiffness	2 m	2	1	None	No	Improved	27 m
87	3 year, 1.2 kg, Maltese, F	Proprioceptive ataxia, Tic, hyperesthesia	9 m	1	2	None	No	Improved	27 m

Abbreviations: CM/SM, Chiari-like malformation and syringomyelia; F, female; FMD, foramen magnum decompression, FS, female spayed; M, male; MN, male neutered; TM, titanium mesh.
This table presents the clinical characteristics, pre- and postoperative findings, and outcomes of 100 small breed dogs treated with FMD and TM based cranioplasty for CM/SM. Data include breed distribution, age at surgery, bodyweight, clinical signs, duration before surgery, presence of CM and SM, severity of CM and SM, concurrent medical treatments, postoperative complications, and clinical outcomes assessed at final follow-up.

confirmed the intentional gap between the TM and the FMD surface (Figure 2).

3.4 | Outcomes

Postoperative follow-up consisted of CT imaging at 6 months to evaluate implant stability and confirm the deliberate gap (Figure 3), followed by structured telephone interviews with owners at regular intervals to monitor neurologic status and symptom recurrence. Based on these assessments, 76 dogs (87%, 76/87) demonstrated sustained clinical improvement in neurologic signs during a median follow-up period of 35 months (range: 27–73 months). No dogs required revision surgery at the decompression site, and the remaining 11 dogs (13%) showed partial recurrence of clinical signs and required continued medical therapy; all of these dogs were included in the 6-month postoperative CT evaluation. In addition, several dogs that experienced delayed recovery were noted to have postoperative weight gain during long-term follow-up, based on owner-reported bodyweight changes at recheck visits and follow-up interviews, although no statistical comparison was performed.

4 | DISCUSSION

This report demonstrates that modified TM technique is a safe and effective surgical treatment for small-breed dogs diagnosed with CM/SM. Among the 87 dogs evaluated, 87% (76/87) exhibited postoperative improvement in clinical signs consistent with SM, without any intraoperative or immediate postoperative complications. None of the dogs required revision surgery at the decompression site, indicating durable and stable outcomes. These results, together with the high rate of postoperative improvement, support the role of surgical intervention in dogs whose clinical signs are not adequately controlled with medical therapy alone.[3,4,19] Notably, most non-improved dogs were 6 years of age or older at the time of surgery, suggesting that disease chronicity and age-related reduction in neural plasticity may have contributed to the limited recovery observed in these cases.

A key consideration in this report is the documented timeframe for postoperative deterioration, which has been reported to occur at a minimum of 3 to 7 months post-FMD.[4,19] Informed by this knowledge, we established the 6-month follow-up as a critical benchmark to screen for early recurrence and to evaluate the technique's initial efficacy. Based on this, the present report extended follow-up to a median of 35 months, allowing rigorous evaluation of the technique's sustained efficacy in addressing the chronic recurrence challenges that have previously limited the success of FMD. While postoperative MRI could have provided a more detailed evaluation of neural structures, it was not performed due to anesthesia duration and metal artifacts. However, CT offered adequate resolution to confirm implant stability, verify the intended gap, and rule out compressive scar tissue without the risks associated with prolonged anesthesia. All patients underwent preoperative CT to evaluate skull and occipital bone morphology, which facilitated surgical planning. Immediate postoperative CT and radiography under general anesthesia enabled confirmation of implant positioning and allowed real-time revision if necessary, though no cases required such intervention. Owners were advised to obtain follow-up CT imaging approximately 6 months postoperatively; these scans demonstrated sustained implant stability and absence of compressive scar tissue. For subsequent long-term monitoring, structured telephone interviews with owners were used, with a median follow-up of 35 months (range: 27–73 months). Long-term follow-up also revealed that postoperative weight gain appeared to be associated with delayed recovery. This finding suggests that maintaining appropriate bodyweight should be considered an important aspect of postoperative management to optimize recovery.[10,19]

The modified TM technique used in this report relied solely on TM fixation without the addition of PMMA. The use of PMMA was avoided due to anatomical constraints and potential thermal injury in small-breed dogs.[4,6] Although previous studies proposed that external PMMA application may reduce recurrence by limiting scar tissue formation,[4,21] previous reports have suggested that the most clinically significant scarring tends to occur internally between the titanium mesh and the cerebellum, where PMMA provides minimal benefit.[19,23] Moreover, stable implant fixation was consistently achieved with cortical screws alone, suggesting that PMMA may not be essential for adequate stability in small-breed dogs. A sufficient and strategically planned gap (5-6 mm) was maintained between the TM and the cerebellar surface to promote gradual tissue ingrowth and the formation of a stable biological barrier. This surgical approach, based on intraoperative anatomical assessment, was designed to promote stable decompression and reduce the possibility of internal tissue adhesion, although verification of scar tissue formation was beyond the scope of this study. The implant was positioned to ensure anatomical compatibility and functional safety without compromising cervical motion. These technical adaptations—modified TM technique, strategic implant spacing, and immediate postoperative imaging—collectively produced a safe and anatomically appropriate outcome.

Although the modified TM technique was not previously validated in a prospective trial, each dog was managed according to the standard clinical indications of the time, without any prior intention to investigate outcomes prospectively. The modification represents a pragmatic adaptation of an established FMD protocol, applied in response to anatomical constraints commonly encountered in small-breed dogs. We assessed the safety and effectiveness of the modified TM technique through immediate postoperative imaging and well-planned long-term follow-up, while still keeping the study observational in nature. The consistent observation of favorable outcomes subsequently led to this retrospective study, allowing systematic evaluation of the clinical utility of the modified TM technique without contravening ethical standards for prospective research.

These results collectively indicate that the modified TM technique, which eliminates the need for PMMA and provides an anatomically compatible reconstruction for small-breed dogs, yielded favorable and durable outcomes in this large clinical series. Nevertheless, given the retrospective design and absence of a control group, we recognize that comparable success has been achieved with other well-established techniques, including the use of ovine intestinal submucosa (SIS) or autologous fat grafts placed over the decompression defect. Therefore, while the present findings support the safety and practicality of this technique, the optimal surgical method should be determined by the surgeon's experience and the individual patient's anatomy. Future prospective or biomechanical studies may help clarify whether titanium mesh confers additional long-term benefits beyond other graft materials.

AUTHOR CONTRIBUTIONS

Park SS, DVM, PhD: Design of the study, suitable medical records, recorded demographic information, compiled all data, interpreted data, analyzed data, drafted and revised the manuscript. Park JY, DVM: Interpreted data, drafted and revised the manuscript. Han HJ, DVM, PhD: Interpreted data and provided scientific, in-line editing of the manuscript, drafted and revised the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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