



Penetrating airgun spinal cord injury in 23 cats (1998–2022)

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Abstract

Objectives The aim of this study was to evaluate and describe airgun spinal cord injuries (SCIs) in cats.

Methods Records of cats presented at the Companion Animal Clinic of Aristotle University of Thessaloniki with neurological deficits associated with a 4.5 mm airgun projectile (AGP) SCI were included. Only cats with lodged projectiles in the spinal canal were included in the present study. Cats were categorised into groups according to the neurological grade, management, season of presentation and projectile location.

Results A total of 23 cats were included in this retrospective study. There were one cervical (C), 17 thoracolumbar (T) and five lumbosacral (L) airgun SCIs. The presence of the projectile in the spinal canal was confirmed by radiographic imaging. Of the cases, 44% were presented in autumn, which was the most frequently presenting season. Surgical management was elected in 20/23 (87%) of the cats, 1/23 (4.3%) were managed conservatively and 2/23 (8.7%) were euthanased owing to poor prognosis without treatment. The neurological grades were V and III in 83% and 4% of the cats, respectively. The remaining cats (13%) had asymmetrical neurological deficits. Conscious movement was regained in 30% of surgically treated cats; spinal walking in 20% and 50% were unimproved. Micturition restoration was not observed in most of the cases.

Conclusions and relevance Airgun spinal injuries result in severe mobility and micturition disorders in cats. As a result of the small sample size, it is uncertain whether the outcome may be influenced by surgical or conservative management.

Keywords: Spinal cord injury; airgun projectile; surgical management; spinal walking

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Introduction

Road traffic accidents and falls are considered the most common causes of spinal cord injury (SCI) in humans, cats and dogs.^{1–7} Although external SCI due to road traffic accidents and falls from a height is thoroughly described in veterinary medicine,^{5,6,8} there is a paucity of information in the English veterinary literature concerning SCIs in cats, secondary to gunshot wounds.^{9–12} SCI induced by ballistic projectiles is considered uncommon in domestic animals, particularly in cats. An incidence rate of 1.8% is reported according to the American College of Veterinary Emergency and Critical Care Veterinary Committee on Trauma.¹³ It is reported in human medicine that although gunshot injuries are considered penetrating, neurological deficits may occur even in spinal cord concussion caused by the projectile and lead to extended SCI.^{14,15} Literature regarding the type of projectile-induced SCI in cats is scarce.^{1,10,13,16} In the few published case reports, spinal

cord penetration is reported caused by airgun projectiles (AGPs).^{9,11,12} Broadly used AGPs often weigh 0.5–1 g with a calibre of 4.5–5.5 mm. According to the literature, muzzle velocities in the range of 305–610 m/s or lower are categorised as low energy. The muzzle velocity of air-powered guns is in the range of 46–366 m/s (1000–2000 feet/s). The energy of the fired projectile can be influenced by both speed and mass according to the principle $E = 1/2 mV^2$

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(where m = the mass of the bullet and V = the velocity).^{17–19} Primary penetration of human skin occurs when the AGP's velocity reaches 120–300 ft/s.¹⁷ Bone penetration is rare owing to projectile deformation according to experimental *in vitro* beef bone studies.^{20,21} In an experimental *in vitro* study, fractures of thinner bones were reported.²⁰ In smaller animals, such as cats, there are no specific management guidelines if penetrating projectile SCIs occur. Even in human medicine, there is a continuous debate about SCI management caused by projectiles. Surgical or conservative management is elected depending on the neurological status of the patient and the coexisting tissue injuries. Surgical projectile removal is strongly suggested in patients with T12 and caudally lodged projectiles and associated SCIs, since motor recovery may be influenced by spinal decompression.^{14,22}

The aim of the present study was to retrospectively review the management and motor recovery of 23 cases of AGP SCI in cats.

Materials and methods

Medical records from cases that presented at the Companion Animal Clinic of Veterinary Medicine school in Aristotle University of Thessaloniki were retrieved after searching the clinics archive. The cats included in the study were presented with acute neurological deficits attributed to AGP SCIs between November 1998 and September 2022. All cats included sustained penetrating SCIs from 4.5 mm calibre projectiles. Only cases with sufficient information about neurological status (before and after treatment), sufficient radiographic examination (lateral and dorsoventral projection), management (conservative or surgical), follow-up and outcome (voluntary/involuntary mobility/paraplegia/euthanasia) were included. Radiographic suspicion of bone penetration was considered when the AGP extended into the spinal canal on both the lateral and the dorsoventral projections and was confirmed upon evaluation of the surgical reports. The cases were categorised into five groups depending on neurological severity according to the Modified Frankel Scoring (MFS),²³ after reviewing the neurological examination sheets.²³ According to the projectile location, the cases were categorised into three groups: cervical, thoracic and lumbar. Three additional categories followed according to the elected management: euthanasia, conservative treatment and surgical treatment. Moreover, cats were separated into four groups depending on the season they presented: winter (December to February), spring (March to May), summer (June to August) and autumn (September to November).

The outcome was assessed based on follow-up information that was obtained through neurological re-evaluation at the time of suture removal approximately 14 days postoperatively and through re-examinations or telephone calls thereafter.

Results

A total of 23 cats were included in the study. Patient characteristics are included in Table 1. Of the 23 cats, 13 (56.5%) were male (3/13 [23%] cats were male castrated) and 10 (43.5%) were female (3/10 [30%] were female spayed). The mean (\pm SD) age was 27.39 ± 10.99 months. All cats received a standard medical management protocol that included intravenous fluids, antibiotics and an anti-inflammatory dose of steroids or non-steroidal anti-inflammatory drugs (NSAIDs). In all cases, urinary bladder catheterisation with an indwelling catheter or manual evacuation tailored to the needs of each case was performed.

There was one cervical injury presented with deficits related to a C6–T2 lesion, 17 thoracic injuries where the cats were paraparetic or paraplegic with T3–L3 deficits and five lumbar injuries where the cats were paraparetic or paraplegic with L4–S3 deficits. The most common injured spinal area was the thoracic area (17/23, 74%). There was no concomitant abdominal or other injury. All entrance holes were found on the dorsal trunk and as pellets were lodged in the tissue, no exit wound existed. Moreover, all the cats that were admitted to the clinic had only dorsal or dorsolateral injuries. According to the medical records, no spinal instability associated with the projectile SCI was reported in any of the cases.

As far as the season that cats were presented in the clinic is concerned, 4/23 (17%) were presented in winter, 5/23 (22%) in spring, 4/23 (17%) in summer and 10/23 (44%) in autumn.

Imaging studies included plain radiographs in lateral and dorsoventral positions in all patients (Figure 1). In all cats (100%), the AGP protruded in the spinal canal in both perpendicular radiography views.

All the cats had varying degrees of upper or lower motor neuron dysfunction (Table 1). Of the 23 cats, 19 (82.6%) were classified as having grade V neurological deficits and 1/23 (4%) cat had grade III neurological deficits. All cats experienced urinary and faecal incontinence on presentation.

Of the 23 cats, 20 (87%) had undergone surgery (group S) by the time haemodynamic stability was assessed, but the exact time between the AGP SCI and surgery was not known (Table 2). Out of 20 surgically treated cats, 14 (70%) were included in the thoracic group, 5/20 (25%) in the lumbar group and 1/20 (5%) in the cervical group. In all surgical cases, the exact location of the projectile that was identified via radiographic examination was confirmed during projectile removal. In 17/20 (85%) cases, hemilaminectomy was performed over the depressed vertebrae lamina. In the remaining 3/20 (15%) cases, the location of the projectile in the spine was initially located by following the fistula that was produced and removal was achieved through hemilaminectomy. The entrance hole was visible after shaving the affected

Table 1 Patient characteristics, month of presentation, neurological deficits, location of the affected spinal cord area, elected management and outcomes (n = 23)

Number	Sex (castrated/spayed)	Breed	Age (months)	Neurolocalisation	Grade (MFS)	Group/AGP location	Management	Outcome
1	M (castrated)	DSH	12	Tetraparesis C6–T2 Urine faecal continence partially restored	Left IV, right II	C (C6)	S	Voluntary walking
2	M	DSH	24	Paraplegia T3–L3	V	T (T4)	S	Spinal walking
3	F	DSH	36	Paraplegia T3–L3	V	T (T6)	S	Spinal walking
4	M (castrated)	DSH	72	Paraplegia T3–L3	V	T (T6)	S	Spinal walking
5	M	DSH	60	Paraplegia T3–L3	V	T (T12)	S	Paraplegia
6	M	DSH	5	Paraplegia T3–L3	V	T (T11)	S	Paraplegia
7	M	DSH	12	Paraparesis T3–L3 Urine faecal continence partially restored	Left II, right IV	T (T11)	S	Voluntary walking
8	M	DSH	6	Paraplegia T3–L3	V	T (T11–T12)	S	Euthanasia intraoperatively
9	F (spayed)	DSH	12	Paraplegia T3–L3	V	T (T12)	S	Paraplegia
10	F	DSH	24	Paraplegia T3–L3	V	T (T12)	S	Paraplegia
11	M	DSH	7	Paraplegia T3–L3	V	T (T13)	S	Paraplegia
12	M (c)	DSH	24	Paraplegia T3–L3	V	T (L2)	S	Spinal walking
13	F	DSH	36	Paraplegia T3–L3	V	T (L3)	S	Paraplegia
14	M	DSH	12	Paraplegia T3–L3	V	T (L1–L2)	S	Paraplegia
15	F (spayed)	DSH	120	Paraplegia T3–L3	V	T (L2–L3)	E	–
16	M	DSH	24	Paraplegia T3–L3	V	T (L2–L3)	E	–
17	F	DSH	48	Paraplegia T3–L3	V	T (L2)	S	Paraplegia
18	M	DSH	42	Paraplegia T3–L3	V	T (L3)	Co	Paraplegia
19	F (spayed)	DSH	30	Paraplegia L4–S3	V	L (L6)	S	Paraplegia
20	M	DSH	6	Paraplegia L4–S3	V	L (L5)	S	Voluntary walking
21	F	DSH	3	Paraparesis L4–S3 Urine faecal continence partially restored	III	L (L6–L7)	S	Voluntary walking
22	F	Mixed Persian	6	Monoplegia L4–S3	Left normal, right V	L (L6)	S	Voluntary walking
23	F	DSH	9	Paraplegia L4–S3	V	L (L5)	S	Voluntary walking
			27.39 ± 10.99*					

*Values are mean ± SD

AGP = airgun projectile; C = cervical; Co = conservative; DSH = domestic shorthair; E = euthanasia; F = female; L = lumbar; M = male; MFS = Modified Frankel Scoring; S = surgical; T = thoracic

area (Figure 2). In all surgically treated cases, the projectile was retrieved and it was confirmed that the calibre was 4.5 mm (Figure 3). Spinal cord inspection followed, and when myelomalacia was highly suspected owing to macroscopic liquefaction of the spinal cord and extended intradural haemorrhage, euthanasia was elected. After

debridement and irrigation, the wound was closed routinely. Postoperatively, all patients received beta-lactam antibiotics for a period of 10 days and an anti-inflammatory dose of steroids or NSAIDs. The urinary bladder was expressed to manually void urine or catheterised with an indwelling catheter while the cat was hospitalised.

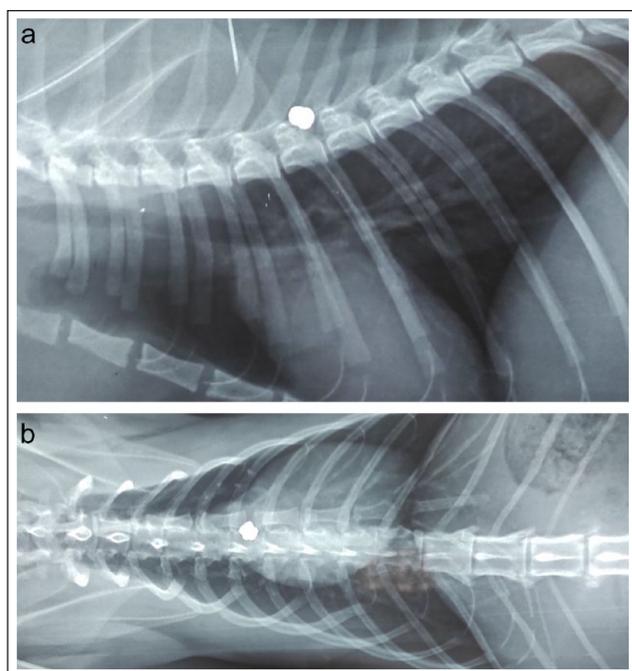


Figure 1 (a) Lateral radiograph showing the lodged airgun projectile (AGP) in the sixth thoracic vertebrae (patient 4); (b) dorsoventral radiograph showing the lodged AGP in the sixth thoracic vertebrae (patient 4)

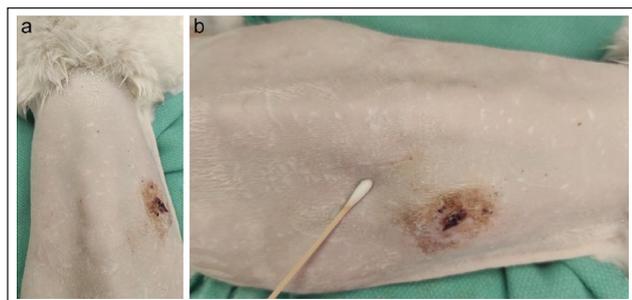


Figure 2 (a) The projectile entrance hole can be seen on the right thoracic side of the cat (patient 17); (b) the cotton swab indicates the vertebrae (L2) in which the projectile was lodged (patient 17)

Rehabilitative care was offered three times daily during hospitalisation.

Of the 23 cats, three (13%) did not undergo surgery and all of them were included in the thoracic group (group T). Two out of three (66.6%) cats were euthanased at the request of the custodian or owing to signs of respiratory



Figure 3 Airgun projectile after it was retrieved (patient 17). Blade (no. 10, 41.7 mm) shown for scale

muscle paralysis and forelimb plegia as well as clinical signs of progressive myelomalacia resulting in a poor prognosis (group E) and in 1/3 (33.3%) cats, the custodian elected for conservative treatment (group Co).

Of the 23 cats, four (17.4%) had asymmetric neurological dysfunction and had intact pain sensations in either one or both legs on the side opposite to where the projectile was located. One of the four (25%) aforementioned cats was included in group C, one (25%) was included in group T and the last two (50%) were included in the lumbar group (group L). All four cats were improved after surgical decompression and they improved at least one MFS grade during a period of 7 days postoperatively.

Of 20 cases with severe (grade V) neurological dysfunction that underwent surgery, 13 (65%) were included in group T and 2/20 (10%) cats were included in group L. All cats that exhibited thoracic SCI with symmetrical grade V neurological deficits had spinal cord lacerations (Figure 4). One of the cats in group T (case 8) that underwent surgery was euthanased intraoperatively as a result of suspected myelomalacia due to extended intradural haemorrhage and liquefaction of the spinal cord.

There was no improvement in the neurological grade of cats with loss of deep pain perception, except for one cat in group L (patient 20).

As far as group T was concerned, 16/17 (94%) cats had absent pain perception, and 13/14 (92.8%) cats that underwent surgical intervention were negative for deep pain perception.

Of the 13 patients with absent deep pain perception that were mentioned above, four (30.7%) developed spinal walking approximately 2–4 weeks postoperatively, in contrast to group L where none of the cats with absent

Table 2 Summary of the outcomes of the surgically treated cats (n = 20)

Number of cats	Neurolocalisation	Complete/incomplete SCI	Outcomes
1	C6–T2	–/1	One voluntary walking
14	T3–L3	14/1	Nine unimproved, four spinal walking, one euthanasia, one voluntary walking
5	L4–S3	1/4	One unimproved, four voluntary walking

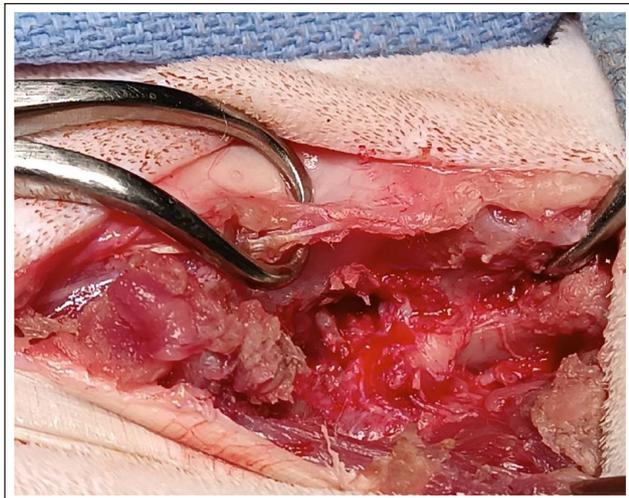


Figure 4 Spinal cord laceration visible through the surgical site, after the airgun projectile was retrieved (patient 17)

deep pain perception developed spinal walking. Of those four cats, one (25%) was euthanased 2 years later as a result of unrelated pathology as reported by the custodian. Micturition continence was partially established in one (25%) of them and mechanical urinary bladder expression was performed in the remaining three (75%) cats by every cat's custodian.

Of the 20 surgically treated cats, nine (45%) developed voluntary or involuntary mobility after surgery and 5/9 (55.5%) of neurologically unimproved cats were euthanased at the custodians' request owing to a poor prognosis within 10 weeks postoperatively. Of 20 cats, six (30%) improved to conscious movement. Four of them were included in group L (66.6%), one in group C and one in group T. In the aforementioned group L, 2/4 (50%) cats had asymmetrical neurological deficits, 1/4 (25%) had improvement in only the left hind limb and in 1/4 (25%) urinary incontinence remained despite the gait improvement. The rest of the cats developed partial bladder and faecal control. Partial urinary and faecal continence was reported in only 3/20 (15%) survivors; in the rest of the cats (17/20, 85%), urinary and faecal incontinence persisted.

There were no instances of wound infection or signs compatible with tetanus in any of the cases. In addition, no lead toxicity or projectile migration was reported in the cat that was treated conservatively.

Spinal stabilisation was not indicated as no instability was suspected.

Discussion

Gun projectiles may damage the spinal cord and the intensity of the SCI may be influenced by the velocity, trajectory, size and material of the projectile and by the distance and type of the tissue targeted.^{15,17,19,24} Although a firearm licence is mandatory for high-velocity guns,

no legal restriction is indicated in Greek law (Law No 2168/93 paragraphs 1 and 7) about the possession of airguns, which are considered low-velocity guns. In Greece, airguns can be acquired without a legal firearm licence. This results in their increased popularity among untrained and sometimes juvenile operators. The frequency of airgun injuries in humans is constant at approximately 2000 per year in the UK and 10 times more in the USA.²⁵ The exact incidence rate of AGP injuries in cats remains unknown. In this study, we investigated the type of SCIs resulting from AGPs with a 4.5 mm calibre in cats. The primary objective was to evaluate the outcomes of motor recovery in combination with the type of management selected for each patient. Bone penetration was consistently observed and confirmed in the 20 surgical cases in our study, often accompanied by dural and spinal cord lacerations. This finding could be attributed to the thinner paraspinal tissue and bone structures of cats in comparison with humans. In human medicine, SCIs caused by penetrating trauma are associated with high-velocity guns. The injuries seen in our series were possibly due to AGPs at the end of their flight (shot from a distance) since there was no severe soft tissue damage in any of our patients. Despite the possible long distance and the low velocity, the projectile size relative to the cat's spinal canal may cause severe neurological deficits as reported in the present study, according to the surgical findings and neurological examinations. Moreover, the long distance of shooting could possibly explain the absence of concomitant soft tissue and organ injuries as reported in road traffic and fall from height associated SCIs in cats.²⁶ In addition, it was of interest that only dorsal or dorsolateral injuries were reported. Potentially, some explanation for this finding could be the relative height difference between cats and the airgun operators resulting in dorsal or dorsoventral SCIs. In a retrospective study by Vnuk et al,¹⁰ the most injured region by metal projectiles was the abdominal area, including the lumbar spine. In our study, AGP SCIs were over-represented in the thoracic area of the spinal cord, in accordance with human literature on gunshot spinal injury.^{14,18} In the same aforementioned study, it was observed that most of the cases of metal projectile injuries in cats were recorded in March.¹⁰ In our study, autumn was the season with the highest incidence rate for those cases. In Greece, the length of the day is longer between March and August, specifically in June and July. As a result, the mating rate is excessive at this time of period. Queens' gestation lasts approximately 63–65 days; therefore, the cat population increases between May and October. That may be a reason why most of the cats included in this study were presented to the clinic in the autumn.^{27,28}

Radiographic imaging, CT and MRI were performed to investigate SCIs, paraspinal tissue and organ damage, and projectile localisation.^{9,10,29–31} MRI is available for diagnostic SCIs; however, in cases of penetrating

trauma caused by metal projectiles, the clinician should take into account that if ferromagnetic materials compose the lodged projectile, image distortion, projectile displacement and thermal damage could be observed. On the other hand, in 4.5 mm AGPs that contain mainly lead (Pb), a non-ferromagnetic material, no projectile movement or image distortion was noted in previous studies, although thermal damage cannot be excluded.^{29,31}

CT is the main diagnostic modality used to identify and classify morphological bone and soft tissue damage in SCIs.³⁰ In particular, in SCIs caused by rifle bullets, CT is recommended after radiography to improve projectile localisation and identification of paraspinal tissue damage.¹⁸ In our study, only plain radiographs in two orthogonal views were performed. Radiographic imaging is used in everyday clinical practice and could be applied in SCI investigation caused by metal projectiles.^{9–11} The exact projectile location could be determined by plain lateral and dorsal radiographic imaging in all cases. Radiographs were also evaluated for possible spinal instability taking into consideration Denis' three-column theory for spine stability after trauma.³² According to Besalti et al,³³ a prognosis can be influenced by spinal instability in cats with spinal trauma. No spinal instability was noted in any of the cases included in our study, a finding attributed to the fact that the cats sustained SCIs due to dorsal and dorsolateral traumas caused by the AGP. This led to a dorsal and dorsolateral entry point in the spinal canal through the middle and lateral part of the lamina; thus, no surgical stabilisation was required and prognosis was influenced only by the neurological deficits caused by the SCI. In contrast to other forms of trauma, airgun spine injury is less likely to result in spinal instability.^{18,34} In cats with suspected spinal injuries, lateral survey radiographs of the whole spine should be obtained to evaluate spinal stability.²⁶ In our study, radiographs were conducted for neurological deficit investigation; when an AGP was found on lateral radiographs, a dorsoventral radiograph followed in order to establish the exact location of the projectile. When the AGP was found, protruded in the spinal canal in both orthogonal radiography views, the SCI was attributed to the penetrating trauma.

The scope of surgery includes debridement of the projectile track and removal of soft tissue, bone, projectile and projectile fragments from the spinal canal, along with visualisation and decompression of the spinal cord.^{9,11,14,24} Conservative or surgical management options for projectile SCIs in human medicine are elected by the clinician after evaluating the patient's neurological status. There is no debate on the need for surgical decompression of the spinal cord in human patients with incomplete neurological deficits caused by projectiles.^{14,22,35} In those cases, spinal decompression should be performed as soon as possible, as it is reported that early decompression may

result in better outcomes.¹⁴ Although the outcomes of surgical removal of the embedded projectiles in SCIs in cats remains unknown, in our study a better outcome was reported in cases with incomplete neurological deficits on presentation and in cases with lumbar SCI. From the cats that developed voluntary mobility, cases 1, 7, 21 and 22 were improved neurologically and were ranked at least one MFS grade lower during a period of 7 days postoperatively on re-examination. Whether all patients with complete deficits after SCI should be operated on a subject of controversy in human medicine.^{14,15} In our study, one cat with absent deep pain perception in group T followed conservative treatment, whereas all other cats were treated surgically.

The choice of a conservative or surgical approach should be individualised for every case and no standard approach has been recommended to date. The superiority of surgical intervention and projectile removal seems to be evident in human patients experiencing SCIs below T12 that involve the cauda equina and may contribute to motor recovery.^{14,22} Our outcomes are in accordance with those reported in the human literature about better outcomes in human patients with lumbar SCIs. The main difference between the neuroanatomical aspects of the spinal cord between humans and cats is that the spinal cord in humans ends caudally to T12 in comparison with cats, where it ends at the seventh lumbar vertebra. Considering this, although all cats included in the study in group L exhibited SCIs involving the spinal cord and not the peripheral nerves of the cauda equina, voluntary kinetic recovery of the hindlimbs could be achieved.³⁶ In our study, surgically treated cats with lumbar (L4–S3) SCIs resulted in 80% (4/5 cats) in conscious motor recovery (cases 20–23). Meanwhile in group T, conscious motor recovery was reported in only 2/13 (15.4%) cats and only in cases with incomplete SCIs.

Four cats in our study that exhibited grade V neurological deficits on presentation and postoperatively in group T developed involuntary walking without deep pain recovery, referred to as spinal walking. None of those cats or the rest of the cases included in the present study received extensive physiotherapy. The implementation of extensive physiotherapy in cats with absent pain perception with thoracic SCI may contribute to spinal walk acquisition, as reported in the veterinary literature.³⁷ In accordance with the veterinary literature, although cats were able to walk, bladder control was not restored in any of those cats.³⁷ Nine paraplegic cats had no signs of motor recovery or bladder control after surgery. Although the follow-up period consisted of 2 months for the four cats and 2 years or more for the others, the neurological status of the cats remained unchanged.

The first limitation of the present study is its retrospective nature. In addition, the duration of the spinal cord compression could not be identified because the exact

time between the SCI caused by the AGP until surgical intervention remains unknown. No conclusion could be drawn about the surgically treated cats in comparison with medically treated cats owing to the limited number of cases of AGP SCIs treated conservatively.

Conclusions

In our study, voluntary motor recovery was achieved in approximately 33% (6/20) of the surgically treated cats with SCIs due to AGP. Spinal walking was observed in only thoracic SCIs in 20% (4/20) of all cats. Although voluntary or involuntary motor reacquisition could be achieved in 50% of the cats, bladder dysfunction persisted in many of the cases. Surgical intervention may be beneficial in asymmetrical SCIs in cats and result in voluntary motor recovery.

Conflict of interest The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Ethical approval The work described in this manuscript involved the use of non-experimental (owned or unowned) animals. Established internationally recognised high standards ('best practice') of veterinary clinical care for the individual patient were always followed and/or this work involved the use of cadavers. Ethical approval from a committee was therefore not specifically required for publication in *JFMS*. Although not required, where ethical approval was still obtained, it is stated in the manuscript.

Informed consent Informed consent (verbal or written) was obtained from the owner or legal custodian of all animal(s) described in this work (experimental or non-experimental animals, including cadavers, tissues and samples) for all procedure(s) undertaken (prospective or retrospective studies).

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