Acute spinal cord injuries (ASCI) in dogs are common and mainly result from intervertebral disk extrusion (IVDE) or traumatic injuries. Recovery rate from ASCI is variable and depends on the severity of the spinal cord damage, rate of onset of clinical signs, and type of treatment. Considering the difficulty of objectively establishing the extent of the spinal cord damage, it is generally accepted to use the absence of pain perception as the most important indirect sign to assess complete functional spinal cord transection. Absence of pain perception is classically associated with a severe to poor prognosis for functional recovery of voluntary locomotion. A recent study on paraplegic TL dogs with absent pain perception due to IVDE did not identify prognostic factors for any of the investigated variables, including age, corticosteroid administration, early surgical treatment, and severity of compression. Few studies described the treatment and the outcome of paraplegic dogs without pelvic limb pain perception, and only one assessed the long-term outcome (>6 months) describing a small percentage of dogs (11%) regaining the ability to walk without pain perception.

Spinal walking (SW) is the term commonly used to define the acquisition of an involuntary motor function in paraplegic mammals affected by a complete thoracolumbar (TL) spinal cord lesion. SW is a reflex gait, resulting from complex dynamic interactions between the pelvic limb locomotor central pattern generator (CPG) and proprioceptive feedback from the body in the absence of superior control by the brain after complete spinal cord damage. CPG is the network of interconnected interneurons in the spinal cord gray matter that modulates motor neuron activity for the generation of gait. Lumbar CPG, which displays a rostrocaudal excitability gradient for rhythmogenic...
capacity, influences the alpha-motor neurons activity via short propriospinal pathways, located in the fasciculus proprius.\textsuperscript{5,13} In experimental trials, spinal locomotion is well described in cats and showed that treadmill training exercise could improve the recovery of autonomous motor function after complete and incomplete spinal cord injury.\textsuperscript{14–20} Less consistent information is available for dogs.\textsuperscript{20–23}

To the authors’ knowledge, there is no published information on the effect of physiotherapy in the development of successful spinal walking in dogs under field conditions.

The aim of this study was to evaluate the number of TL paraplegic dogs without pain perception that developed an autonomous SW gait after a period of intensive physical rehabilitation training. Attention was focused on the identification of potential parameters (age, weight, type and site of lesion, duration of clinical signs, hospitalization during physiotherapy, onset of physiotherapy) associated with involuntary pelvic limb motor function recovery.

Materials and Methods

Medical records of paraplegic dogs with TL spinal cord lesion due to acute IVDE or exogenous trauma, referred to the Physiotherapy and Rehabilitation Centre “Dog Fitness” (Reggio Emilia, Italy) between 2005 and 2014, were retrospectively reviewed.

Dogs were included in the study if they had a medical record documenting paraplegia and absent pelvic limb pain perception, after physical and neurological examinations by the referring neurologist and at the admission at the Physiotherapy and Rehabilitation Centre; a spinal cord lesion confirmed by magnetic resonance imaging (MRI) or computed tomography (CT); a complete protocol of physiotherapic rehabilitation treatment; and had absence of pelvic limb pain perception at the end of the physiotherapic rehabilitation treatment.

For the purpose of this study, absence of pain perception was defined as lack of a conscious response (e.g., crying, looking around, or similar reaction) to the application of heavy pressure to the pelvic limb digits with forceps.\textsuperscript{5} Dogs showing tail wagging in response to the owner’s presence or voice were excluded by the study. SW was defined as the ability to develop an unassisted voluntary gait. Specifically, dogs were considered spinal walkers if they could walk for a potentially infinite period of time and, in case of falling, were able to regain unassisted the standing posture and continue to walk.

Clinical records of each dog included the following parameters: signalment, clinical presentation (by Olby scoring system\textsuperscript{24}), type (acute IVDE or traumatic vertebral luxation/fracture) and site of the lesion, presence of surgery (hemilaminectomy in dogs with IVDE or stabilization in dogs with exogenous trauma), type of hospitalization regimen (full-time or day-hospital) during the physical rehabilitation and outcome.

A personalized physiotherapy protocol was settled based on the specific needs of each dog, including the following five basic categories of exercises, differently arranged: passive range of motion (ROM) exercises, flexor reflex and crossed extensor reflex stimulation, active assisted exercises, electrostimulation (only in case of postspinal shock hypotonia) and hydrotherapy on underwater treadmill (UWTM).

Each physiotherapic treatment lasted approximately 60 minutes and was performed on all dogs every day, twice per day regardless of their status of hospitalization. UWTM was started on admittance or, in case of surgical management, at least 5 days after surgery at the speed of 1.8 km/h. UWTM bouts lasted 5 minutes at the beginning of the treatment and were progressively increased up to 15 minutes when dogs started to show pelvic limbs movements.

The duration of the cycle of physiotherapeutic treatment was tailored to each single dog depending on the physiotherapist’s opinion in terms of deciding whether to continue or stop the treatment. Thus, the duration of the entire physiotherapeutic treatment was considered either the time elapsed between the start of the rehabilitation and the acquisition of independent spinal walking gait or the period between the start and the discontinuance of physio therapy due to the failure in achieving SW.

All statistical analyses were performed with a commercially available statistical data analysis program (MedCalc\textsuperscript{26} version 12.2.1.0). Assessment of data for normality was calculated by applying the D’Agostino-Pearson test. Data with normal distribution were expressed as mean and standard deviation (SD), while when normality is rejected, median with 95% confidence interval (95% CI) was used. Values of \( P < .05 \) were considered significant. A Wilcoxon signed-rank test \( (P < .05) \) was used to consider the influence of the anatomic localization of the lesion on development of SW.

Dogs were divided into two groups: the spinal walking group (SW group), including dogs that achieved the ability to develop an autonomous unassisted involuntary locomotion, and the no-spinal walking group (No-SW group), including dogs that did not develop an autonomous unassisted involuntary locomotion.

In order to detect specific variables significantly associated with the development of SW gait, age, sex, weight, BCS, type of lesion (acute IVDE or trauma), hospitalization during the physical therapy treatment, and time between loss of pain perception and start of physiotherapeutic treatment were compared between the SW and No-SW groups by a binary logistic regression. Variables that meet a cutoff of \( P < .15 \) at the univariate analysis were entered into a multivariate logistic regression. The odds ratio (OR) and 95% CI were calculated from the final model. A receiver operating characteristic (ROC) curve was used to select the optimum cutoff value of the variables to discriminate dogs with SW gait from dogs with No-SW gait.

Results

Eighty-one dogs met the inclusion criteria and were included in the study. Figure 1 describes the process of selection of the cases. Descriptive data of the general population are detailed in Table 1. Table 2 reports the descriptive data of the SW and No-SW groups.

SW Group

At the end of the cycle of physiotherapeutic treatment, 48 dogs (59%) developed an autonomous spinal locomotion. Of the 48 SW dogs, 31 (64%) underwent surgery. The spinal cord lesion was situated between Th4-Th5 and L2-L3. The most frequently affected site (20 dogs) was at the level of Th12-Th13 (Fig 2).

Median time between loss of pain perception and the beginning of physical therapy was 9.5 days (range: 2–210), and the median duration of physiotherapeutic treatment was 75.5 days (range: 16–350). Thirty-nine dogs (81%) had full-time hospitalization.
The median duration between the start of physiotherapeutic treatment and the ability to stand up unassisted, recorded in 29 dogs, was 20 days (range 2–150).

**No-SW Group**

At the end of the cycle of physiotherapeutic treatment, 33 dogs (41%) did not develop an autonomous spinal locomotion. Of the 33 No-SW dogs, 30 (91%) underwent surgery. The spinal cord lesion was situated between Th7-Th8 and L2-L3. The most frequently affected site (13 dogs) was at the level of Th12-Th13 (Fig 2).

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**Table 1.** Data of the general population.

| Dogs  | 81 |
|-------|----|
| Breeds (most represented) | Mixed breed (n = 29; 36%), Dachshund (n = 16; 25%), Yorkshire Terrier (n = 5; 6%), Cocker Spaniel (n = 5; 6%) |
| Age m: 60 months (range: 8–144; 95% CI: 48–66) |
| Sex Male: 41 (50.6%) (C: 4; 3.7%) Female: 30 (37%) (N: 7; 8.6%) |
| Weight m ≤10 kg: 6; >10 kg: 35 |
| BCS m: 5 (range: 3–8; 95% CI: 5–5) |
| Dogs with IVDE 54 (66%) |
| Dogs with traumatic injuries 27 (34%) |
| Dogs with full time hospitalized 65 (80%) |
| Delay in onset of physiotherapy* m: 12 days (range: 2–1260; 95% CI: 8.21–19.38) |
| Duration of physiotherapy m: 74 days (range 10–360) |
| Dogs affected by IVDE 34 (71%) |
| Surgical management 27 (56%) |
| Medical management 7 (15%) |
| Traumatic injuries 14 (29%) |
| Surgical management 4 (8%) |
| Medical management 10 (21%) |
| Hospitalization 39 (81%) |
| Delay in onset of physiotherapy* m: 9.5 days (95% CI: 6.12–12.77) |
| Duration of physiotherapy m: 75.5 days (95% CI: 58.94–81.79) |

*Days between the onset of paraplegia and the beginning of physical therapy.

m, median; BCS, body condition score; C, castrated, N, neutered.

The median duration between the start of physiotherapeutic treatment and the ability to stand up unassisted, recorded in 29 dogs, was 20 days (range 2–150).

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**Table 2.** Spinal Walking (SW) and No-Spinal Walking (No-SW) groups.

| Spinal Walking (SW) Group | No-Spinal Walking (No-SW) Group |
|---------------------------|-------------------------------|
| Dogs 48 (59%) | 33 (41%) |
| Breed (most represented) | Mixed breed (n = 17; 35%), Dachshund (n = 8; 17%), Miniature poodle (n = 5; 10%) |
| Age m: 54 months (95% CI: 48–66) | m: 72 months (95% CI: 52.93–84) |
| Sex Males: 23 (C: 2) | Males: 21 (C: 1) |
| Females: 25 (N: 5) | Females: 12 (N: 2) |
| Weight m: 7.3 kg (95% CI: 7–29.6 kg) | m: 10 kg (95% CI: 8.24–12.59) |
| ≤10 kg: 16; >10 kg: 17 | ≤10 kg: 16; >10 kg: 17 |
| BCS m: 5 (95% CI: 5–5) | m: 5 (95% CI: 5–5) |
| Dogs affected by IVDE 34 (71%) | 20 (61%) |
| Surgical management 27 (56%) | 20 (61%) |
| Medical management 7 (15%) | 0 |
| Traumatic injuries 14 (29%) | 13 (39%) |
| Surgical management 4 (8%) | 10 (30%) |
| Medical management 10 (21%) | 3 (9%) |
| Hospitalization 39 (81%) | 26 (79%) |
| Delay in onset of physiotherapy* m: 9.5 days (95% CI: 6.12–12.77) | m: 23 days (95% CI: 11.41–60) |
| Duration of physiotherapy m: 75.5 days (95% CI: 58.94–81.79) | m: 69 (95% CI: 46.64–92.95) |

*Days between neurological deficit onset and the beginning of physical therapy.

m, median; BCS, body condition score; C, castrated, N, neutered.
Median time between loss of pain perception and the beginning of physiotherapy was 23 days (range: 2–1260), and the median duration of physiotherapeutic treatment was 69 days (range: 10–370). 26 No-SW dogs (79%) had full-time hospitalization.

On univariate analysis, comparison between the SW and the No-SW groups showed that age was significantly lower in SW group (\( P = 0.002 \); OR = 4.14; 95% CI: 1.61–10.66). Early start of physiotherapy was positively associated with achievement of SW gait (\( P = 0.024 \); OR = 2.81; 95% CI: 1.12–7.01).

Weight (\( P = 0.089 \)), BCS (\( P = 0.051 \)), full-time hospitalization (\( P = 0.78 \)), type (\( P = 0.33 \)), and site of the lesion (\( P = 0.93 \)) were not significantly associated with development of SW.

By a multivariate logistic regression, younger age and lower weight were significantly associated with development of SW (\( P = 0.012 \); OR = 5.66; 95% CI: 1.69–18.94 and \( P < 0.001 \); OR = 5.09; 95% CI: 1.54–16.78, respectively). ROC curve showed that dogs aging \( \leq 60 \) months and dogs weighting \( \leq 7.8 \) kg had higher possibilities to achieve SW (95% CI: 0.53–0.75; sensitivity: 72.9%; specificity: 60.6% and 95% CI: 0.63–0.83; sensitivity: 54.2%; specificity: 93.9%, respectively) (Figs 3 and 4).

**Discussion**

In veterinary literature, SW is rarely described in dogs and most of studies report SW gait development in training cats experimentally spinalized. This study shows that paraplegic dogs with absent pain perception undergoing intensive physiotherapeutic treatment have good chance (59% in our population) to develop an unassisted involuntary gait. Our study found that younger age (\( \leq 60 \) months on ROC curve analysis) was positively associated with development of SW. Literature does not provide comparable data, except for
experimental studies. In the eighties, it was demonstrated that adult dogs could develop SW gait after experimental mid-thoracic spinal cord transection, disputing the earlier statements that functional recovery of locomotion in TL spinalized animals depended upon their very young age at the time of transection. A recent study on the outcome of paraplegic dogs without pelvic limb pain perception did not find any significant association with age. In another study, younger age was associated with failure rather than better recovery of the motor function.

Our analysis showed that lightweight dogs (≤7.8 kg on ROC curve analysis) have a significantly better possibility of developing SW. Despite the empiric belief that lightweight dogs with acute spinal cord lesion have a better outcome, literature does not provide specific information concerning the association between weight and outcome, including development of SW. It is worth mentioning that one 26 kg dog with IVDE developed complete transection of the T9-T10th spinal cord segment during the course of the injury. Consequently, exercise is considered to play an important role in facilitating the CPG in the development and outcome of paraplegic dogs. Ethical reasons and the retrospective nature of our study did not prevent the possibility of having dogs developing SW. Nevertheless, the high percentage of dogs developing SW suggests that, also under field conditions, specific motor training could play an important role in facilitating motor recovery after ASCI. While confirmed on univariate analysis, our multivariate analysis failed to confirm the association between early start of physiotherapy and development of SW. Nevertheless, the high percentage of dogs developing SW suggests that, also under field conditions, specific motor training could play an important role in facilitating the CPG in the development of SW. Furthermore, inclusion criteria excluded dogs that developed myelomalacia, possibly affecting the percentage of dogs that gained SW. Finally, physiotherapeutic treatment of the No-SW group was stopped according to the subjective physiotherapist’s judgment on the lack of response.

In conclusion, our study demonstrates that a percentage of paraplegic dogs without pelvic limb pain perception undergoing a cycle of intensive physiotherapy treatment can acquire SW gait.

Veterinarians and owners, when facing a catastrophic event such as an ASCI leading to paraplegia without pelvic limb pain perception, should be aware of the possibility that their pets can develop SW gait and encouraged to act consequently. Further studies are necessary to objectively assess the role of intensive physiotherapy in the acquisition of SW gait in paraplegic dogs without pain perception.

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