Evaluation of ventral root reimplantation as a treatment of experimental avulsion of the cranial brachial plexus in the dog

P. MOISSONNIER, Y. DUCHOSSOY, S. LAVIEILLE and J.C. HORVAT

SUMMARY
This in vivo experimental study was carried out 1/ to evaluate the ability of dog spinal neuron to grow an axon into reimplanted brachial plexus ventral root, and 2/ to assess the functional outcome after root reimplantation. The reimplantation of C5, C6 and C7 ventral rootlets was carried out after their avulsion in 6 dogs (group 1) and three other dogs were used as sham control (group 2). Axonal regrowth in the roots was assessed by Horse Radish Peroxidase (HRP) retrograde tracing studies and muscular reinnervation was tested by electrophysiology. Functional recovery was evaluated by clinical examination and muscle weight (in comparison to 12 normal dogs cadavers : group 3).

HRP-tracing methods demonstrated axonal regrowth into the reimplanted roots by (moto)neurons confined in the ipsilateral ventral horn. In group 1, EMG investigations showed signs of reinnervation and neuronal labelling was observed. In group 2, there were no signs of reinnervation by EMG and no neuronal labelling. In addition, amyotrophy was more severe in group 2. No sign of functional recovery was observed in either of the two groups. Our findings demonstrate that root reimplantation may promote muscular reinnervation in the dog after brachial plexus avulsion.

KEY-WORDS : brachial plexus - avulsion - dog.

RÉSUMÉ
Évaluation de la réimplantation radiculaire ventrale en tant que traitement des avulsions expérimentales de la partie craniale du plexus brachial chez le chien. Par P. MOISSONNIER, Y. DUCHOSSOY, S. LAVIEILLE et J.-C. HORVAT.

Cette étude expérimentale a été réalisée dans le but 1/ de connaître la capacité des neurones médullaires du chien d’émettre un axone au sein de la racine ventrale d’un nerf spinal réimplantée dans la moelle épinière et, 2/ d’évaluer le résultat fonctionnel de cette réimplantation.

La réimplantation des radicelles ventrales des racines C5, C6 et C7 a été réalisée après leur avulsion chez 6 chiens (groupe 1). Trois autres chiens ont été opérés selon le même protocole mais sans que la réimplantation soit laissée en place (chiens témoins opérés : groupe 2). La repousse axonale a été étudiée au moyen d’un marquage rétrograde par la péroxydase du raifort (HRP) et par étude électrophysiologique. La récupération fonctionnelle a été appréciée par l’examen clinique et par la pesée des muscles (effectuée comparativement à des muscles prélevés sur 12 chiens témoins non opérés : groupe 3).

Le marquage rétrograde a démontré que des (moto)neurones spinaux situés dans la corne ventrale ipsilatérale étaient capables d’émettre un axone au sein de la racine réimplantée chez les chiens du groupe 1. Dans ce même groupe, l’examen électromyographique montrait qu’une reconnexion avec l’effetieur musculaire s’était produite. Dans le groupe 2, aucune réinnervation n’a pu être observée à l’examen électrophysiologique et aucun neurone n’a été marqué. Aucun signe de récupération fonctionnelle n’a été observé quel que soit le groupe. Ces résultats montrent que la réimplantation radiculaire peut promouvoir une réinnervation musculaire après avulsion du plexus brachial chez le chien.

MOTS-CLÉS : plexus brachial - avulsion - chien.

Introduction

Brachial plexus injuries are occasionally encountered in the veterinary practice, especially in the dog [14, 27, 32, 37]. Most of them are traction lesions which usually result from road traffic accidents. Neurological deficits depend on the severity of brachial plexus damage. The brachial plexus arises from the ventral branches of C5 to T2 spinal nerves. These branches contribute in a variable manner to the brachial plexus formation. C5 is incorporated in the plexus in 24.19 % of cases [2].

Functionally, the dog brachial plexus can be divided in two parts [32]. The cranial part of the plexus consists of the C5, C6 and C7 ventral branches : it controls shoulder and elbow flexion. The caudal part of the plexus is more complex and commands elbow extension, and carpus and digit mobility. Ventral branches of the cervical and thoracic spinal nerves contribute in a variable manner to the brachial plexus [32]. The suprascapular and subscapular nerves arise from the union of the ventral branches of the fifth (rarely), sixth and seventh spinal nerves. The musculocutaneous nerve receives contributions from the C6, C7 and C8 ventral branches of the cervical nerves but rarely from T1.
The so-called avulsion of the brachial plexus (ABP) is usually complex with both spinal nerve root neurapraxia or axonotmesis and avulsion of one or several roots from the spinal cord [15, 32]. The avulsion can take place in the cranial part, in the caudal part or in both parts of the plexus.

While peripheral nerve neurotmesis can be treated with a good functional outcome using routine surgical principles for peripheral nerve injuries [14], root avulsion was until now beyond repair, not only because of the size of the gap separating the spinal cord from the avulsed rootlets, but also because of a fundamental lack of axonal regrowth and extension from neurons injured in the central nervous system (CNS) [1]. Thus, ABP results in permanent paralysis of the muscles innervated by the avulsed roots and of sensory loss in the corresponding dermatomes. In the dog [32] and in mankind [13], its treatment is only palliative.

Recent experiments have shown that CNS neurons can grow and extend axons if an autologous peripheral nerve segment is grafted in their immediate vicinity [1, 36]. In the adult dog, this axonal regrowth can reach at least 10-15 cm within a four-month period [26]. These new data justify a new surgical strategy in the treatment of ABP: ventral root reimplantation (VRR). In laboratory animals, motoneurons of the cervical spinal cord have been shown to reinnervate the corresponding reimplanted ventral roots [6, 7, 8, 16, 17, 20, 35]. Yet, a number of problems still remain to be solved before a routine clinical application of VRR can be performed: 1/ the large distance between the cervical spinal cord and the muscular effectors might be a limiting factor for anatomical and functional restoration, a factor that is less significant in small animals such as rats, 2/ in the experimental models, roots are generally avulsed just before reimplantation. Thus, this procedure does not take into account the time between accidental avulsion and surgery, nor its consequences on spinal cord, roots or muscle function. The dog represents an interesting model for carrying out restorative procedures and for studying the consequences of the surgical approach and VRR trauma, and the benefits of VRR (group 1) compared to spontaneous healing after cranial BPA (group 2). The dogs used in group 1 and 2 were female beagle dogs aged of 2 to 3 years with a mean body weight of 12.3 kg (range 8.5 to 14.8 kg). Group 3 was made up of 12 fresh mixed-breed dog cadavers with a mean body weight of 13.4 kg (range 6.2 to 18.9 kg) in which left and right biceps brachialis, supraspinatus and infraspinatus muscles mass was measured. Our aim with this control group was to confirm that the muscle mass of the right and the left forelimb were identical (that the dog is not right- or left-handed). This would be confirmed if the left/right muscle weight ratio was statistically identical to 1.

SURGICAL APPROACH TO THE VERTEBRAL COLUMN

The lateral surgical approach was initially developed through dissection studies and has been previously described [21, 24].

The 9 female adult beagle dogs used were anaesthetized and routinely prepared for an aseptic surgery of the left forelimb, shoulder and caudal cervical region. The C5, C6 and C7 ventral branches, with their corresponding nerve roots and spinal cord segments, were approached as previously described [25]. The contribution of the C5 ventral branch to the plexus and of the C8 ventral branch to the suprascapular and subscapular nerves were checked by dissection and by direct electric stimulation. A bipolar electrode was positioned on the surface of the nerve after it had been isolated from the surrounding tissue and a 5mA-stimulation was applied. We considered that the branch contributed to the nerves if

Material and methods

The surgical, behavioural and electrophysiological procedures were all approved by the scientific committee of our Institution.

MODEL DESIGN

For this long term study, in order to avoid limb self mutilation, we chose to work on a model in which some roots (and corresponding nerves and muscles) can be isolated from the rest of the plexus and thus studied independently. We denervated the cranial part of brachial plexus. For this purpose, we cut the eventual contributions of C5 or C8 to the suprascapular and subscapular nerves. The C8 and T1 contributions to the musculocutaneous nerve were left intact to avoid neurological deficits in the caudal part of the plexus. Thus, the axonal regrowth observed in the suprascapular and subscapular nerves arise only from those roots that were reimplanted.

To evaluate the benefits of VRR, we used 3 groups of dogs. Group 1 was formed of 6 dogs in which VRR was performed. Group 2 (3 dogs) was a sham control group. A surgical approach and VRR was performed but the reimplanted roots were cut distally to the reimplantation site. The comparison between these two groups led to an appreciation of the consequences of the surgical approach and VRR trauma, and the benefits of VRR (group 1) compared to spontaneous healing after cranial BPA (group 2). The dogs used in group 1 and 2 were female beagle dogs aged 2 to 3 years with a mean body weight of 12.3 kg (range 8.5 to 14.8 kg). Group 3 was made up of 12 fresh mixed-breed dog cadavers with a mean body weight of 13.4 kg (range 6.2 to 18.9 kg) in which left and right biceps brachialis, supraspinatus and infraspinatus muscles mass was measured. Our aim with this control group was to confirm that the muscle mass of the right and the left forelimb were identical (that the dog is not right- or left-handed). This would be confirmed if the left/right muscle weight ratio was statistically identical to 1.

In order to determine if the reimplantation technique can be used routinely in the case of spontaneous BPA seen in clinical practice, the present study was designed:

1) to evaluate axonal regeneration into the reimplanted ventral roots
2) to demonstrate the re-establishment of functional motor units via an electrophysiological study
3) to compare the restoration of function after reimplantation with the outcome of untreated root avulsion.

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a. Nerve stimulator, Aesculap, Germany.
macroscopic muscle contraction was observed. If they were found to contribute to the nerves, the stimulated branch (or contribution to the nerve) were cut to prevent axonal sprouting from the remaining axons coming from C8 or C5 which were not subjected to VRR. Hemilaminectomy of the caudal cervical column gave access to the dura. Before durotomy, the dogs were given methylprednisolone sodium succinate (30 mg/kg intravenously).

ROOT AVULSION AND REIMPLANTATION

The dura was first secured and pulled laterally with four stay-sutures, then opened longitudinally with micro-scissors under the dissecting microscope, dorsally to the dorsal roots (fig. 1A). To visualise more clearly the ventral rootlets, a gentle and limited rotation of the spinal cord was achieved by placing two stay-sutures into the dentilicate ligament and then exerting mild traction on them. The dorsal and ventral rootlets of C6 and C7 were avulsed from the cord with a curved microsurgical needle holder. The traction was exerted in a direction parallel to the course of the spinal root (fig. 1B). The effect was checked visually to determine whether the avulsion was total. Immediately after injury, two slits were made in the meningeal membranes and spinal cord tissue on the left side, ventrally and dorsally to the dentilicate ligament (fig. 1C). This incision extended into the ventral horn of the gray matter. The dorsal slit involved the white matter only. The avulsed rootlets were reimplanted into the slit with microforceps and a small piece of Surgicel® was left in place to cover them in order to prevent bleeding and in order to secure the rootlets in position (fig. 1D). The dogs were then randomized as 1/ reimplanted group (in which reimplantation was left in place) and 2/ sham control group (in which nerves were transected before they penetrated into the muscles). The recording needle was positioned into the muscles (supra and infra- spinatus, biceps and triceps brachialis, radial carpal extensor, interosseous).

FUNCTIONAL EVALUATION

Behaviour, gait and neurological function were assessed every day by one of the authors.

Under general anesthesia, conventional EMG recordings [10, 34] were made at 1, 2, 4 and 6 months postoperatively, with concentric needle electrodes connected to an EMG device. These studies were conducted in all forelimb muscles and, in particular, in those innervated by the lesioned roots (supraspinatus, infraspinatus and biceps brachialis). EMG was also recorded in the corresponding muscles of the normal (right) forelimb. Spontaneous electrical activity following denervation was quantified using a simple scale:

- 0: no spontaneous activity (no recording)
- +: moderate spontaneous activity in some location of the muscle belly
- ++: moderate spontaneous activity in every location of the muscle belly
- +++: marked spontaneous activity in every location of the muscle belly

Evoked muscular potentials (EMP) were recorded (in mV) following supramaximal stimulation of C7 ventral branch by a 0.45 x 50 mm negative electrode (53508, Médélec, France) introduced percutaneously, caudally to the transverse process of the sixth cervical vertebra. The positive electrode was positioned near the left scapula. The recording needle was positioned into the muscles (supraspinatus, infraspinatus and biceps) after nerve stimulation.

RETROGRADE AXONAL TRACING WITH HRP

Six months after VRR, the dogs were anaesthetized and the craniomedical region of the left shoulder was approached [18]. The musculo-cutaneous, suprascapular and subscapular nerves were isolated from the surrounding connective tissues and transected before they entered the muscles. The cut end of the nerves were placed on a plastic sheet and surrounded with petroleum jelly to avoid tracer contamination of the neighboring tissues. Then, a small pad of gelfoam soaked in 30 % Horse Radish Peroxidase (HRP) solution, was left in contact with the tip of the nerve for one hour [4]. After tracer application, the exposed area was washed out several times with saline and the wound was closed in layers. For this second invasive procedure, pain was controlled again by ketoprofen administration.

MORPHOLOGICAL METHODS

Forty eight hours later, the dogs were sacrificed by barbiturate overdose. The heart was approached via a medial stenotomy and the left ventricle was cannulated. The dogs were perfused with 15 liters of an isotonic heparinized saline solution followed by 8-10 liters of 3 % glutaraldehyde in 0.1 M phosphate buffer at 4° C. The cervical spinal cord was then dis-
FIGURE 1. — Semi-schematic representation of the avulsion-reimplantation procedure of one ventral root. The spinal cord is cross sectioned to show the depth of reimplantation of the ventral rootlet. (A) The dura matter is incised around the dorsal aspect of the dorsal root. (B) The dorsal root is avulsed from the spinal cord with a needle handler. (C) The avulsed dorsal and ventral rootlets are reimplanted into a slit made in the spinal cord and covered (D) with a small hemostatic sponge (Surgicel®).
The clinical data were in accordance with our previous observations [25]. Immediately after surgery, a flaccid paralysis in the left shoulder appeared in all animals of the group 1 and 2. Regional palpation revealed a severe amyotrophy which developed within weeks in the muscles supplied by the avulsed nerve roots (supraspinatus, infraspinatus and partially in biceps brachialis). Clinically, this amyotrophy was more severe in group 2 in which the muscles were reduced to a thin streak of elastic tissue, contrasting with the bulky appearance of the muscle on the right side. During the first two months after avulsion, none of the dogs used their left limb which would lie along the thoracic wall. Signs of clinical restoration were difficult to appreciate but gradual improvement in the function of the affected limbs occurred in all the dogs. Four months after surgery elbow flexion could be observed but there was no evidence for a difference in the shoulder function between groups 1 and 2.

Most of the dogs exhibited signs indicating damage to long fiber tracts of the spinal cord. Motor (paraparesis, generally left side lateralized), sensory (proprioceptive deficits) and sympathetic (Cl. Bernard-Horner’s syndrome) signs were observed. Left hindlimb patellar and flexion reflexes were decreased. Nevertheless, these deficits remained slight, so that the dogs could move themselves independently and be continent 15 days after surgery. Neurological deficits gradually decreased with time but the neurological assessment remained slightly abnormal (mild proprioceptive left side lateralized hindlimb deficits) until the end of the protocol, in all the dogs. There was no Cl. Bernard-Horner’s syndrome at this time.

### ELECTROPHYSIOLOGICAL EVALUATION

Neurophysiological signs of denervation in the left shoulder muscles (spontaneous activity following denervation) were observed in groups 1 and 2. Subsequent evidence of reinnervation (evoked muscular potentials) was only observed in group 1.

EMG recordings made 1 month p.o. revealed fibrillation potentials (+ to ++++) in all left frontlimb muscles normally innervated by the cranial part of the brachial plexus in groups 1 and 2. These potentials decreased at 4 months (+ to ++++) and even more at 6 months (0 to ++) in both groups. A weak spontaneous activity was also recorded in all muscles of the left forelimb. These potentials had disappeared at 4 months. This observation could not be statistically analysed.

EMPs were measurable in all muscles (group 1) and in all muscles except the supra and infra-spinatus (group 2).

In the supraspinatus and infraspinatus muscles of the group 1 dogs, the evoked muscular potentials were generally of low amplitude. They increased with time, in particular between the second and third EMG examinations. The maximum EMP response in the reinnervated muscles was recorded in the infraspinatus muscle (amplitude was 80% of right side recording which was considered as normal).

No late potentials were recorded. Table I gives the complete results of electrophysiological examinations and figure 2 shows 1 month and 6 month EMP recording in the left supraspinatus muscle of dog 4 (group 1) and dog 9 (group 2).

### MORPHOLOGICAL STUDY

In group 1 dogs, reimplanted C6 and C7 roots appeared, in cross sections, to be embedded in scar tissue and were seen penetrating into the gray matter. In the group 2 dogs, the same roots were found outside the vertebral canal.

Cavitation of the spinal cord (micro and macro cyst formation) was a constant histological finding in both groups. These cysts were located in the gray matter near the intraspinal tip of the reimplanted root as well as at some distance from it (1 to 10 millimeters). They were surrounded by an acellular, amorphous lining membrane. The nerve cells located beside the cysts seemed to be unaffected.

HRP-retrograde axonal tracing resulted in the labeling of left cervical spinal neurons which were located close to the intraspinal tip of the reimplanted roots (figure 3). With regard to their location, size and morphology, most of these labeled cells, dispersed through the ipsilateral ventral horn, were assumed to be motoneurons. In some instances, axons of the labeled cells could be traced towards the implanted root.
### TABLE I. — Results of left forelimb electrophysiological examinations.

<table>
<thead>
<tr>
<th>DOGS (group)</th>
<th>Electro exam</th>
<th>left biceps brachialis muscle</th>
<th>left infraspinatus muscle</th>
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Dogs: number and (group). Group 1 (reimplantation) or group 2 (control). The dogs were randomized in the groups; Electrooexam: electrophysiological examination; EMG (ElectroMyoGraphic examination): spontaneous activity is quantified by the following scale: 0: no spontaneous activity (no recording), +: moderate spontaneous activity in some location of the muscle belly, ++: moderate spontaneous activity in every location of the muscle belly, +++: marked spontaneous activity in every location of the muscle belly, NE: Non Explored (for technical reasons such as postoperative muscle edema); EMP (Evoked Muscular Potential) data are given in mV.

**Table I.** — Results of left forelimb electrophysiological examinations.
There were no labeled neurons in the control group. The number of neurones labeled in these experiments is shown in Table II.

**MUSCLES**

The left supra and infraspinatus muscle amyotrophy was more severe in group 2 than in group 1. Biceps brachialis amyotrophy was not obvious during macroscopic examination.

In the normal dogs, $r_n$ was close to 1 (biceps brachialis: $0.99 \pm 0.06$, supraspinatus: $0.97 \pm 0.05$ and infraspinatus: $1.02 \pm 0.06$).

In the control dogs (group 2), $r_2$ was low (biceps brachialis: $0.38 \pm 0.11$, supraspinatus: $0.13 \pm 0.05$ and infraspinatus: $0.10 \pm 0.04$).

In the reimplanted dogs (group 1), $r_1$ was inferior to $r_n$, but superior to $r_2$ (biceps brachialis: $0.44 \pm 0.15$, supraspinatus: $0.30 \pm 0.09$ and infraspinatus: $0.30 \pm 0.15$). The differences between $r_1$ and $r_2$ are significant for the infraspinatus ($p = 0.05$) and supraspinatus ($p = 0.01$) muscles but not significant for the biceps muscle. The differences between $r_1$ and $r_n$, and $r_2$ and $r_n$ were highly significant for all muscles. Figure 4 gives a schematic representation of these differences.

**Discussion**

This attempt to use ventral root reimplantation (VRR) as a treatment of brachial plexus avulsion (BPA) in the dog clearly demonstrates a reinnervation of the reimplanted roots. The axonal-tracing technique confirms that the regenerating axons come from the cervical spinal neurons. HRP is transported retrogradely through the peripheral nerve and labels, spinal and dorsal root ganglia neurons [23]. It gives the opportunity to know where the neuronal soma corresponding to a given axon is located. In other words, the retrogradely HRP-labeled neurons are those nerve cells which have grown an axon into the nerve root at least up to the site of tracer application. Therefore the present study indicates that root reimplantation into the spinal cord results in axonal regrowth from spinal motoneurons close to the lesion and reimplantation site. This can be explained by the results of experiments previously carried out in rodents [14, 31] where it was established that grafted roots (made of peripheral nerve tissue) act by providing a new microenvironment which appears to be more permissive to axonal regrowth and elongation than the surrounding injured CNS tissue. Furthermore, HORVAT et al. [19] have shown that these regenerating

<table>
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<th>Dogs</th>
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<tr>
<td>8</td>
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**TABLEAU II.** — Number of HP-labeled neurons in the two groups.
axons could reform specific connections with a peripheral muscular target by generating new motor endplates. Our electrophysiological data are in full agreement with these findings.

FUNCTIONAL RECOVERY

Unlike partial (1 or 2 roots) BPA, complete BPA results in a significant neurological deficit such that root reinnervation can be evaluated by clinical tests. Functional recovery, following complete BPA, has been observed in small laboratory animals such as rats [35] or small monkeys [6, 8]. In contrast, functional recovery following partial BPA performed in cats [17], dogs [20] or sheep [16] was difficult or even impossible to assess. However, in our dog model, the cranial part of the plexus can be isolated from the rest of the BP. In these conditions, functional recovery of the infraspinatus and supraspinatus muscles depends exclusively on the reimplantation of the C6 and C7 roots, whereas recovery of the biceps brachial muscle could also be the result of collateralization of

**FIGURE 3.** — Cross section of the cervical spinal cord segment 7 after retrograde neuronal labeling and HRP histochernistry using tetramethyl benzidine (TMB) and counterstaining with neutral red.
A. The reimplanted ventral rootlet (large arrow) penetrates into the ventral horn (VH) of the spinal cord gray matter and is surrounded by large cystic cavities (stars) ; B and C, HRP labeled neurons (small arrows) are those that have grown an axon through the reimplanted ventral rootlet at least up to the site of tracer application. They are located near the intraspinal tip of the reimplanted rootlet and have small black vesicles into their cytoplasm. Scale bars : A = 200 µm ; B and C = 50 µm.
remaining axons originating from the C8 root. Clinical tests have to be developed to appreciate the mobility of the shoulder in the dog. In this study, we have assumed that the presence of electrophysiological signs of reinnervation does not necessarily mean that there is functional recovery, but the repaired motor units we have described, have been shown to connect with the descending pattern of the spinal cord in the rat after electromagnetic cortical stimulation [5] and, thus, to create a functional motor pathway.

RESTORATION OF MUSCLE FUNCTION

The condition of the muscle at the time of reinnervation is crucial for VRR success. Skeletal muscle can substantially recover its ability to contract when it is reinnervated following transection and resuture of its peripheral nerve but a prolonged period of denervation is thought to make denervation changes irreversible [12]. Muscle weight is directly related to muscle function [12]. Muscle paralysis leads to severe muscular fibrosis and complete degeneration [3]. In a frog model it has been shown that a nerve does not lose its ability to reinnervate a muscle but, in contrast, a muscle rapidly loses its ability to become reinnervated [12]. The strength produced by a reinnervated muscle depends on the time elapsed since the muscle was denervated. It has been suggested that following target reinnervation some neurons acquire the capacity to branch and to form large motor units. After a two year period of permanent denervation, the muscle belly becomes phagocytosed and if reinnervation is performed at this time, there is no possibility of success [30]. The extent to which the duration of denervation influences the ability of the neuron and muscle to recover has not been established in the dog. Nevertheless, the re-establishment of appropriate connections following surgery implies axonal regrowth from spinal neurons and to the muscular effectors, through the site of injury. The maximum speed of outgrowth recorded experimentally in the rat, 4.83 mm per day [Earlanger], never seems attainable in man. There is a consensus of opinion as to the range of regeneration speed in man, from 0.5 mm [33] to 2 mm per day [29]. No data is available in the dog but the distance separating the spinal cord and the muscle might be a limiting factor for anatomical and functional restoration. Therefore, we think that reimplantation has to be performed as soon as possible and that functional rehabilitation (with neuromuscular stimulation) has to be planned immediately after surgery to maintain muscle function [9].

RELIABILITY OF THE SURGICAL PROCEDURE

Spinal cord cysts and neuronal death are lesions due to avulsion itself and to the VRR procedure. The functional outcome of the dogs depends on the severity of these lesions. The destruction of the ventral horn of the spinal cord and the replacement of the neuropile by cysts means there is no hope for axonal outgrowth. In our study, there exists a correlation between the severity of the lesions, the number of marked neurons, the intensity of the evoked muscular potentials and the muscle weight. Twenty four neuronal somata were labeled in dog 6 (group 1) which showed the most severe histological spinal cord lesion including large cysts. In this dog, the amplitudes of the evoked muscular potentials were weak, and muscle weight was reduced. We observed that the greater the number the regenerating neurons, the higher are the EMP. The improvement of the reimplantation technique (limitation of haemorrhage, deepness control of root introduction into the gray matter) is expected: 1/ to reduce spinal cord lesion and subsequent postoperative deficits, 2/ increase the number of regenerating axons, 3/ enhance functional recovery.

The current treatment of BPA is only palliative and limb amputation is often proposed [15, 32, 37]. Our results suggest
that an active therapeutic approach for BPA could enhance the functional outcome of this dramatic condition. Therefore, root reimplantation appears to be a very attractive candidate for cranial BPA treatment. For a correct evaluation of gait and functional recovery after VRR, avulsion of the whole brachial plexus studies must be studied. This would correspond more clearly to the clinical presentation where a complete (or causal part) avulsion of the plexus is observed. It would be then possible to know if the function of the extensor muscles, without which the function of the whole of the member is compromised, can be restored.

However, before it can be used routinely, many problems have to be solved such as: 1/ reinnervation does not necessarily result in a functional recovery, 2/ muscle function has to be monitored 3/ the reimplantation technique has to be improved.

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