Cervical ventral slot in rabbits (*Oryctolagus cuniculus*). Piezosurgery versus conventional technique

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**ABSTRACT**

**Purpose:** To investigate the applicability of piezosurgery for cervical ventral slot (CVS), comparing it with the conventional technique of using high-speed burs for bone wear. **Methods:** Thirty rabbits (*Oryctolagus cuniculus*) were divided into two treatment groups (T1 and T2) corresponding to CVS between C3-C4. In T1, the surgery was performed with piezoelectric apparatus, and in T2 with high-speed burs. The evaluated parameters were: duration of each stage of surgery, temperature variations during CVS, visibility of the surgical field, intra and postoperative complications, and anesthetic monitoring. At 14, 28, and 56 postoperative days, five animals from each treatment group were submitted for histopathological study of the surgical site. **Results:** Compared with T2, T1 had more precise bone cut, and better visibility of the operative field, although it required longer total surgical time (p = 0.02) and triggered a greater number of intraoperative complications (p < 0.01), microscopic lesions in the spinal cord (p < 0.05), and transient neurological deficits in the postoperatively (p < 0.05). **Conclusion:** It is necessary to perform surgical planning and have several tips of the piezoelectric instrument available for the safe use of the piezoelectric device in neurosurgery.

**Key words:** Neurosurgery. Piezosurgery. Spinal Cord. Rabbits.

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Introduction

Intervertebral disc disease (IVDD) is a common cause of neurological dysfunction. Ventral slot is the surgical technique of choice of many neurosurgeons for the treatment of cervical IVDD, because it allows direct access to the herniated disc material, has shorter recovery period, and it is technically less demanding than the dorsal approach.

High-speed burs are commonly used to promote vertebral bone wear. The perforation should be performed with caution, considering the changes in the coloration and texture of the bone tissue and identifying the neurovascular structures in order to avoid iatrogenic lesions. However, excessive heat production and the possibility of injury to the adjacent soft tissues, even when the technique is performed cautiously, make these instruments disadvantageous. Hence, piezoelectric technology was developed to address the need for greater safety and accuracy in bone surgeries in comparison to the traditional motorized instruments that were commonplace in surgeries until then.

In piezosurgery, ostectomies are performed with ultrasonic instruments based on the piezoelectric effect. Micrometric vibrations are produced and transferred to the tip of the instrument, and the frequency of these vibrations ranges between 25 and 30 kHz, which can produce a mechanical cutting effect when applied with light pressure on the bone tissue. This particular frequency range ensures selective cutting of only the mineralized tissues, since soft tissues and neurovascular structures require frequencies higher than 50 kHz to be incised.

Given the potential application of piezosurgery, especially in neurosurgery, and the scarcity of literature addressing the applicability of this technique, experimental studies are necessary. Therefore, the goal of this study was to investigate the applicability of piezoelectric surgery in the performance of cervical ventral slot (CVS), using rabbits (Oryctolagus cuniculus) as an experimental model for dogs and cats. For this purpose, the performance of CVS with piezoelectric apparatus and the one of high-speed burs (conventional technique) were compared. We hypothesized that piezoelectric surgery would have better intraoperative performance and superior postoperative results than the conventional technique.

Methods

The present study was conducted with the consent of the corresponding Ethics Committee on the Use of Animals of the Universidade Estadual Paulista "Julio de Mesquita Filho", Jaboticabal Campus (CEUA-FCAV-UNESP), under the number 5.403/16.

Experimental design

Thirty white New Zealand breed of rabbits (Oryctolagus cuniculus) were used. The subjects were healthy adults, of the same age, with the average weight of 3.3 kg. Among them, 16 were female and 14 male.

The animals were divided into two treatment groups, and for each, one of the CVS techniques was performed. For T1, it was performed using a piezoelectric equipment, and for T2 the conventional technique was used, with a spherical drill-bit coupled to the high-rotation motor.

The Mastersonic medical device (VK Driller Equipamentos, São Paulo, SP, Brazil) was used in both treatments, and training for its operation was provided previously. Additionally, both techniques were performed by the same surgeon, alternately between the two treatment groups and in a surgical room at 25ºC.

Each treatment group (T1 and T2) was further divided into three groups: groups A and B at 14 postoperative days (POD), groups C and D at 28 POD, and groups E and F at 56 POD, based on the postoperative time elapsed until euthanasia. The groups A, C, and E belonged to T1 and B, D, and F to T2.

Anesthesia and monitoring

The animals were submitted for preanesthetic medication with acepromazine (0.25 mg/kg, IM), midazolam (2 mg/kg, IM), and pethidine (3 mg/kg, IM), applied to the right pelvic limb. For anesthetic induction, 5% isoflurane was used with the aid of a face mask. Afterwards, all animals were orotracheally intubated and maintained in the anesthetic plane with isoflurane at the rate of 1 to 3%.

During the whole surgical procedure, as fluid therapy, the animals were maintained on continuous infusion of lactated Ringer’s solution at the rate of 10 mL/kg/h. All animals received tramadol hydrochloride (5 mg/kg, subcutaneous) and ketoprofen 10% (1 mg/kg, subcutaneous, every 24 hours) and enrofloxacin 5% (10 mg/kg, subcutaneous, every 24 hours), both for five days.

Anesthesia monitoring was performed with a multiparametric monitor, for the following parameters: heart rate (bpm) and respiratory rate (mpm); systolic, diastolic, and mean arterial pressure (mmHg); oxygen saturation (%); concentration of carbon dioxide at the end of expiration (mmHg), and body temperature (°C). These data, as well as the mean volume of isoflurane and...
fluid therapy required in the procedures, were recorded immediately before, during, and after CVS.

Surgical procedure

After extensive trichotomy of the cervical region, the animals were placed in dorsal recumbency in the surgical gutter. Following rigorous antisepsis, the skin was incised, the subcutaneous tissue and the raphe of the muscles were adequately dissected, allowing the trachea, esophagus, and carotid sheath to be identified and retracted to the left side. The intervertebral space between the third (C3) and fourth (C4) cervical vertebrae was identified by digital palpation, and the muscles were elevated of the ventral face of C3 and C4.

CVS was performed including one-third the length and half the width of the vertebral body of the caudal portions of C3 and cranial of C4. Bone removal was performed in two ways, each corresponding to one type of technique. Therefore, T1 used piezosurgery, in which there was resection with Mastersonic piezoelectric apparatus containing a delicate chisel-type tip, pre-established surgical program with 70W of power (horizontal vibration of the tip), and 80W of modulation (vertical vibration of the tip), whereas for T2 the conventional technique was performed, in which the bone was removed with a carbide steel high-rotation spherical drill of 2 mm in diameter connected to the 1:1 straight hand piece, coupled to the surgical motor of the same Mastersonic device, with rotation of 25,000 rpm and torque of 0.07 N.m. Both treatments received constant irrigation with sterile saline, at room temperature and at the rate of 30 mL/min, according to the technical indication of the equipment, and drainage was performed with a surgical aspirator.

In the T1 animals, slot ventral was performed en bloc, from cortical-to-cortical resection. In the T2 animals, following the principles of the conventional technique, when the internal cortex was reached, the bone removal was interrupted, and a Lucas curette no. 85 was used to remove it. After the conclusion of CVS, the same curette was used in both T1 and T2 animals to remove the remnant of the intervertebral disc (IVD), and any bleeding of the vertebral venous sinus was controlled with a lyophilized collagen hemostatic sponge. Finally, the closure of the soft tissues was performed as routine.

Evaluation of surgical variables and data collection

During the surgical procedures in both treatments, the following variables were evaluated: surgical access time (from skin incision to exposure of the ventral face of C3 and C4), bone wear time, curettage time (IVD), and total time of the CVS procedure, and all of these measurements were performed with a stopwatch. The temperatures of the surgical room, the irrigation solution, and the CVS site were evaluated at three instances: immediately after the surgical access, during the technique, and at the end of the procedure. All the thermal measurements were performed at approximately 15 cm from the surgical site using infrared digital thermometer.

Additionally, the visibility of the surgical field was also assessed using the Likert-type scale, adapted from Farrell et al., in which score 1 means complete visibility, score 2 the presence of discrete bone bleeding and foam formation, score 3 the presence of moderate bone bleeding, controlled with a hemostatic sponge, and score 4 intense bone bleeding, making it impossible to conclude the procedure.

Intraoperative complications

No intraoperative complication was recorded, including cardiac arrhythmias, cardiopulmonary arrest, and venous sinus hemorrhages.

Postoperative neurological evaluation

Complete neurological examination was performed at 12, 24, 48, and 72 hours postoperatively.

Histological evaluation

After the postoperative period scheduled for each group, the animals were submitted for euthanasia. The cervical columns were adequately dissected, prepared for histopathology, and were sent to be processed in the Research Laboratory of the Veterinary Pathology Service. The histological sections were made at the ventral slot site. The reading of these slides was performed without the pathologist knowing which treatment or group was being analyzed. Thus, only at the end of the reading of all the slides, the results were attributed to their corresponding experimental group.

The changes suffered by the spinal cord were evaluated microscopically and staggered in:

- Absent (-): without signs of morphological lesion;
- Mild degree (+): discrete signs of Wallerian degeneration and spherocytes in up to 10% of the spinal cord;
- Moderate degree (++): Wallerian degeneration, spherocytes, malacia, and Gitter cells comprising 11 to 25% of the spinal cord;
Surgical variables

The intraoperative data are presented in Table 1. According to the Student’s t-test, only three variables showed significant differences (p < 0.05) between the treatment groups: curettage duration (p = 0.04), total procedure time (p = 0.02), and the difference between the initial and final temperatures at the CVS site during irrigation (p = 0.02). The parameters were higher in T1.

According to Mann-Whitney test, the visibility of the surgical field was also statistically different (p < 0.01) between the two treatment groups. The use of piezoelectric apparatus promoted better visibility than the conventional technique.

Surgical times

In T1, the mean bone wear time was 8 min 43 s, and in T2, the mean bone wear time was reduced throughout the procedures. Although the difference was not statistically significant, bone wear time was higher in piezosurgery than in the conventional technique.

The curettage time was significantly higher in T1 than in T2. In the first procedures, it was very similar in both treatments. However, subsequently, there was a substantial increase in the curettage time in piezosurgery, which resulted in an increase in the average time.

The total time for CVS followed the trend of bone wear time (r = 0.89); in T1, because of the direct influence of curettage time (r = 0.94), the mean time for CVS was greater than that in T2, although it was not statistically significant.

Table 1 - Mean and standard deviations of the variables evaluated in cervical ventral slot (CVS) between C3-C4 in rabbits with piezosurgery (T1) and conventional technique with high-speed burs (T2)*.

| Variables                              | T1               | T2               |
|----------------------------------------|------------------|------------------|
| Weight (kg)                            | 3.35±0.32 a      | 3.29±0.59 a      |
| Access time (min)                      | 9 min 24 s ± 3 min 0 s a | 8 min 2 s ± 2 min 35 s a |
| Time of use of the appliance (min)     | 8 min 43 s ± 2 min 18 s a | 7 min 35 s ± 3 min 20 s a |
| Curettage time (min)                   | 6 min 8 s ± 3 min 27 s a | 4 min 0 s ± 1 min 39 s b |
| CVS time (min)                          | 14 min 51 s ± 5 min 18 s a | 11 min 35 s ± 3 min 46 s a |
| Total time (min)                       | 24 min 34 s ± 5 min 31 s a | 19 min 37 s ± 5 min 30 s b |
| Room temperature (ºC)                  | 24.57±1.84 a     | 25.11±1.75 a     |
| Temperature of the irrigation solution (ºC) | 23.70±1.52 a     | 24.23±1.87 a     |
| Temperature before CVS (ºC)            | 31.85±1.73 a     | 30.81±2.53 a     |
| Temperature during CVS (ºC)            | 27.59±2.26 a     | 27.39±2.00 a     |
| Temperature after CVS (ºC)             | 26.59±2.08 a     | 26.56±2.39 a     |
| Difference between the temperatures before and after the CVS (ºC) | 5.25±1.09 a     | 4.25±1.20 b     |

CVS time: time of use of the apparatus added to the curettage time; *different letters show differences between treatments (p < 0.05) by the Student’s t-test.
As the total time was directly related to the time of surgical access and CVS, it was significantly higher in T1 than in T2. Therefore, the use of piezoelectric apparatus resulted in longer surgical procedures than that when the conventional CVS technique was used.

**Temperatures**

The temperatures of the surgery room and the irrigation solution were not significantly different between the groups since they were adequately controlled to maintain them at approximately 25 °C.

Regarding the temperatures at the site of the osteotomy before, during, and after CVS, it was observed that the temperatures in piezosurgery were slightly higher than those with the conventional technique, especially before CVS, but without statistical significance. Therefore, when the difference between the initial and final temperatures was calculated, the final result was statistically significantly higher in T1 than that in T2.

**Visibility of the surgical field**

According to Mann-Whitney test, the visibility of the surgical field was significantly (p < 0.01) better in T1, in which discrete bone bleeding was observed in only one animal. In T2, discrete bone bleeding and foam formation were observed in four animals, and moderate bone bleeding was seen in two animals and required a hemostatic sponge.

**Intraoperative complications**

The only intraoperative complication in both groups was vertebral venous sinus hemorrhage during the curettage stage. According to Mann-Whitney test, it was more frequent in T1 than in T2 (p < 0.01). Hemorrhage was observed in four cases in T1 and two cases in T2.

**Postoperative neurological evaluation**

Transient proprioceptive deficits in the postoperative period were observed in three animals (7, 9 and 15) in T1, with recovery within 72 hours of the surgery. None of the animals in T2 developed postoperative neurological changes.

**Anesthetic monitoring**

The parameters related to anesthesia monitoring before, during, and after CVS are presented in Table 2.

### Table 2 - Mean and standard deviation of anesthesia monitoring data before, during and after cervical ventral slot (CVS) between C3-C4 in rabbits with piezosurgery (T1) and conventional technique with high-speed burs (T2).

| Treatment                      | Before CVS     | During CVS     | After CVS      |
|--------------------------------|----------------|----------------|----------------|
| **Heart rate (bpm)**           |                |                |                |
| T1                             | 198.83 ± 19.17 | 184.77 ± 21.12 | 185.16 ± 17.40 |
| T2                             | 196.12 ± 17.27 | 193.86 ± 15.45 | 185.98 ± 24.31 |
| **Respiratory rate (mpm)**     |                |                |                |
| T1                             | 25.21 ± 5.24   | 25.20 ± 7.21   | 24.35 ± 7.80   |
| T2                             | 23.36 ± 6.64   | 25.47 ± 4.08   | 25.70 ± 4.35   |
| **Systolic arterial pressure (mmHg)** |            |                |                |
| T1                             | 105.87 ± 9.63  | 102.76 ± 11.47 | 106.15 ± 9.97  |
| T2                             | 104.81 ± 10.92 | 101.28 ± 11.66 | 102.54 ± 6.89  |
| **Diastolic arterial pressure (mmHg)** |            |                |                |
| T1                             | 47.82 ± 11.99  | 45.28 ± 11.74  | 45.97 ± 10.68  |
| T2                             | 45.72 ± 9.35   | 43.78 ± 7.70   | 43.93 ± 8.92   |
| **Mean arterial pressure (mmHg)** |            |                |                |
| T1                             | 74.16 ± 7.52   | 71.82 ± 6.86   | 72.28 ± 5.14   |
| T2                             | 73.57 ± 8.45   | 70.59 ± 9.10   | 70.77 ± 7.13   |
| **Oxygen saturation (%)**      |                |                |                |
| T1                             | 98.71 ± 0.41   | 98.66 ± 0.46   | 98.59 ± 0.57   |
| T2                             | 98.73 ± 0.50   | 98.84 ± 0.30   | 98.52 ± 0.67   |
| **Concentration of carbon dioxide at the end of expiration (mmHg)** |            |                |                |
| T1                             | 47.08 ± 6.95   | 45.91 ± 4.06   | 45.69 ± 5.59   |
| T2                             | 48.04 ± 4.87   | 47.08 ± 6.24   | 47.70 ± 4.27   |
| **Body temperature (ºC)**      |                |                |                |
| T1                             | 38.90 ± 0.67   | 38.68 ± 0.70   | 38.38 ± 0.75   |
| T2                             | 38.72 ± 0.59   | 38.39 ± 0.75   | 38.08 ± 0.80   |
| **Isoflurane (%)**             |                |                |                |
| T1                             | 1.85 ± 0.43    | 1.60 ± 0.50    | 1.40 ± 0.53    |
| T2                             | 1.79 ± 0.39    | 1.57 ± 0.36    | 1.31 ± 0.24    |
| **Fluid therapy (mL/h)**       |                |                |                |
| T1                             | 33.68 ± 3.24   | 41.91 ± 31.62  | 33.68 ± 3.24   |
| T2                             | 34.68 ± 5.73   | 40.04 ± 23.53  | 35.27 ± 7.15   |
There were no significant differences (p < 0.05) between the groups in any of these parameters (Student’s t-test).

**Histopathological analysis**

**Group A (T1): 14 postoperative day**

On the 14th postoperative day, vascularized connective tissue and moderate inflammatory infiltrate of the chronic active type were observed at the site of the lesions. The bone window was still open, but filled with granulation tissue, and there was a great deal of bone debris enveloped by the inflammatory reaction. The muscle tissue near the CVS site was degenerate and had syncytium (Fig. 1a). At the edges of the lesions, the spongy bone was hyperplastic. The impairment of the spinal cord ranged from mild to moderate (Fig. 1 b-c, Table 3).

**Group B (T2): 14 postoperative days**

There were no signs of inflammation in the cicatricial focus in 3/5 animals (8, 20 and 26), and the signs were discrete in the other two (2 and 14)—consisting mainly of small amounts of monocytes, macrophages, lymphocytes, and plasma cells. Skeletal muscle degeneration was mainly represented by the formation of syncytium and edematous segmented muscle fibers and was detected in 4/5 animals (2, 8, 14 and 20). Additionally, mild-to-moderate hemorrhage at the CVS site was present in 4/5 animals (2, 8, 14 and 20). With respect to the spinal cord, there were no morphological alterations in 2/5 (2 and 20) animals, while in the other three (8, 14 and 26) the morphological changes were mild (Table 3).

**Group C (T1): 28 postoperative days**

On the 28th postoperative day, at the site of the lesion, vascularized connective tissue was mature with occasional collagenization and sparse inflammatory cells composed mainly of mononuclear cells. Adjacent to the scars, the muscle fibers were enveloped by connective tissue in an isolated manner and, underlying the scar, there was a bony callus filling the window, in which it varied from discrete to exuberant (Fig. 1 d-f). Regarding the analysis of the spinal cord, only one sample was without morphological alterations, and the others were classified as moderate (Table 3).

**Group D (T2): 28 postoperative days**

In this group, the same pattern of soft tissue healing as in group C was observed along with discrete amounts of foreign body-type giant cells in the superficial regions of the scars. The histological findings of the bony callus

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**Figure 1** - Photomicrographs of the histopathological study of rabbits (*Oryctolagus cuniculus*) submitted cervical ventral slot (CVS) between C3-C4 with piezosurgery (T1) and conventional technique with high-speed burs (T2). (a) Histological section of the surgery site (animal 19, T1, Group A): note the degenerated muscle fibers (arrows) and surrounded by mononuclear inflammatory cells (Masson’s trichrome, x40); (b) Histological section of the spinal cord (animal 7, T1, Group A): note the axonal vacuolization, spherocytes (short arrows) and Gitter cells (hematoxylin and eosin, x20); (c) Histological section of the spinal cord (animal 13, T1, Group A): note the axonal vacuolization, spherocytes and Gitter cells (hematoxylin and eosin, x10); (d) Histological section of the spinal cord (animal 9, T1, Group C): note the lesion area (arrows) (hematoxylin and eosin, x1); (e) Previous figure in the highest magnification (x5); (f) Previous figure in higher magnification (x20): note the axonal vacuolization, spherocytes and Gitter cells (Sampling date: September 29, 2017).
were also similar to those in group C. The notoriety of this group was due to the morphological characteristics of the nervous tissue, with total preservation of histology in all five samples (Fig. 2a, Table 3).

**Group E (T1): 56 postoperative days**

In this group, a scar was observed from the subcutaneous tissue to the bone callus. The bone callus varied from discrete to exuberant, with cartilaginous metaplasia and the presence of fibrocartilage in a random and inconstant manner in the samples. The newly formed bone was spongy, and the gaps had viable hematopoietic cells. There were no histopathological changes in the spinal cord in 3/5 animals (5, 11 and 17). However, in two animals (23 and 29), such changes were graded as mild (Fig. 2 b-d, Table 3).

**Table 3 - Histopathological changes classified according to the type and degree of lesion present in the spinal cord of rabbits after cervical ventral slot (CVS) with piezosurgery (T1) and conventional technique with high-speed burs (T2)*.**

| Treatment | Experimental group | Animal | Type of injury | Degree |
|-----------|--------------------|--------|----------------|--------|
| T1        | A*                | 1*     | Discrete Wallerian degeneration | +      |
|           |                   | 7*     | Malacia with spherocytes and Gitter cells | ++     |
|           |                   | 13     | Malacia with spherocytes and Gitter cells | ++     |
|           |                   | 19     | Absent | -      |
|           |                   | 25     | Malacia with spherocytes and Gitter cells | ++     |
| T2        | B*                | 2*     | Absent | -      |
|           |                   | 8*     | Discrete Wallerian degeneration | +      |
|           |                   | 14*    | Discrete Wallerian degeneration | +      |
|           |                   | 20     | Absent | -      |
|           |                   | 26*    | Discrete Wallerian degeneration | +      |
| T1        | C*                | 3*     | Technical artifact** |        |
|           |                   | 9*     | Malacia with spherocytes and Gitter cells | ++     |
|           |                   | 15*    | Malacia with spherocytes and Gitter cells | ++     |
|           |                   | 21     | Malacia with spherocytes and Gitter cells | ++     |
|           |                   | 27     | Absent | -      |
| T2        | D*                | 4*     | Absent | -      |
|           |                   | 10     | Absent | -      |
|           |                   | 16     | Absent | -      |
|           |                   | 22     | Absent | -      |
|           |                   | 28     | Absent | -      |
| T1        | E*                | 5*     | Absent | -      |
|           |                   | 11*    | Absent | -      |
|           |                   | 17*    | Absent | -      |
|           |                   | 23     | Wallerian degeneration with spherocytes | +      |
|           |                   | 29     | Discrete Wallerian degeneration | +      |
| T2        | F*                | 6*     | Absent | -      |
|           |                   | 12     | Absent | -      |
|           |                   | 18     | Absent | -      |
|           |                   | 24     | Absent | -      |
|           |                   | 30*    | Technical artifact** |        |

*A and B: euthanasia at 14 postoperative days; C and D: euthanasia at 28 postoperative days; E and F: euthanasia at 56 postoperative days; -: absent lesions; +: mild lesions; ++: moderate lesions; +++: severe lesions; *different letters show difference (p < 0.05) by the Mann-Whitney test, in which capital letters represent differences between treatments (T1 and T2) for the experimental groups with the same postoperative period; #animals that presented intraoperative venous sinus hemorrhage; $animals that presented proprioceptive deficits in the postoperative period; **artifact technique indicates a damaged sample during processing, making it impossible to read; #different letters show difference (p < 0.05) by the Mann-Whitney test, in which capital letters represent differences between treatments (T1 and T2) for the experimental groups with the same postoperative period.*
Group F (T2): 56 postoperative days

In this group, the morphological pattern of healing and bone callus were similar to the findings in group E. The morphological characteristics of the spinal cord remained unchanged in 4/4 animals (6, 12, 18 and 24) (Fig. 2 e-f, Table 3).

Therefore, in the present study, a greater number of histopathological spinal cord lesions was observed with piezosurgery—especially at 14 and 28 POD—, that were characterized by malacia, spherocytes, and Gitter cells. In contrast, with the conventional technique, only mild Wallerian degeneration was observed 14 days after the surgery.

Discussion

The piezosurgery allows easy intraoperative operation of its instruments and accurate bone cutting because of the use of ultrasonic microvibrations to perform osteotomies. In contrast, the conventional instruments, such as bone drills and oscillatory saws, work with macrovibrations, which make precise cutting impossible due to the loss of tactile skill and sensitivity of the surgeon12–14. Such differences agree with the findings of this study, which revealed precise and regular osteotomy with the piezoelectric apparatus and irregular elliptical cuts with the conventional technique.

The present study also showed that the total time of piezosurgery was longer than that of the conventional technique. According to Hennet5 and Barone et al.15, piezosurgery usually requires longer surgical time due to the smaller size of its cuts when compared with traditional instruments. Therefore, depending on the structure and bone thickness involved, the duration of the procedure can increase by up to five times16. However, many studies have presented varying results when comparing the surgical times of the two techniques11,15–19. This variation may be related to the type of surgery, structures involved, and instruments used5.

The curettage stage contributed significantly to the higher total piezosurgery time. This was due, in part, to the complete preservation of the intervertebral disc at the end of the corpectomy in T1 group, possibly due to the absence of signs of calcification of this material and deprivation of cut of the non-mineralized tissues by the piezoelectric apparatus. Therefore, it was necessary to use the curette to perform the discectomy, and this excessive manipulation increased the risk of injury to the spinal cord and vertebral venous sinus, as demonstrated by four cases of hemorrhage. Because of such complications in the first few procedures, there was an increase in the surgical time in the others due to greater care being taken for curettage. In contrast, high-speed burs remove any type of tissue and,
of having several tips available, with different angulations and diameters, for more accurate bone cuts\[16,25,26\].

Schaeren et al.\[27\] carried out a study to assess the potential damage of piezoelectric instruments to a peripheral nerve upon direct contact under different forces, and this contact with the nerve was also applied without ultrasonic activation. They conclude that the direct exposure of peripheral nerve to piezoelectric device did not dissect the nerve, but induced structural and functional damage. The frequency and extent of functional damage were higher with increased pressure applied on the nerve, but not by activation of ultrasonic vibration. Therefore, it is believed that this is what happened to the animals in T1 group. The mechanical contact of the tip of the piezoelectric instrument with the spinal cord, and not the mechanism of action of the device, led to reversible structural and functional damage.

In the conventional technique with high-speed burs, great care is taken to avoid the entry of the drill into the vertebral canal, as it is known that its contact with the spinal cord will cause irreversible damage to the neural tissue. Thus, the drill is used only until the internal cortex, and then special instruments are used to complete the spondylectomy and enter the vertebral canal. Therefore, according to our results, the lesser spinal cord damage in T2 group is related to the cautious surgical technique used with the conventional device and not to the safety of the device itself when having direct contact with the nervous tissue.

Therefore, as long as there is no mechanical contact between the tip of the piezoelectric instrument and the spinal cord, it is possible to use this device in neurosurgical procedures safely and promoting precise and en bloc bone cutting, excellent intraoperative visibility and greater dexterity in handling the instrument. Thus, the limitations involve the cost of acquiring the device, the need for preoperative planning to opt for the ideal size tip according to the patient’s size and, consequently, the need to purchase different tips.

**Conclusions**

CVS in rabbits with piezosurgery promoted precise bone cutting, excellent visibility of the operative field and ease of handling of the instrument. However, when compared with the conventional technique, it required a longer total surgical time and resulted in a greater number of intraoperative complications—such as microscopic lesions in the spinal cord—and transient neurological deficits in the postoperative period. It is believed that these injuries were triggered by the mechanical touch of the tip of the piezoelectric instrument in the spinal...
Cervical ventral slot in rabbits (*Oryctolagus cuniculus*). Piezosurgery versus conventional technique

Cord and not by the mechanism of action of the device. Therefore, performing the proper surgical planning and having different tips available, piezosurgery is applicable in neurosurgical procedures.

**Author’s contribution**

Substantive scientific and intellectual contributions to the study: Roscamp M, Minto BW and Dias LGGG; Conception and design: Roscamp M, Minto BW and Dias LGGG; Data analysis and interpretation: Roscamp M, Hataka A and Ferreira DRC; Technical procedures: Roscamp M, Hataka A and Zambon FC; Statistics analysis: Roscamp M; Manuscript writing: Roscamp M and Ferreira DRC; Critical revision: Roscamp M, Hataka A, Zambon FC, Ferreira DRC, Minto BW and Dias LGGG; Final approval: Roscamp M, Hataka A, Zambon FC, Ferreira DRC, Minto BW and Dias LGGG.

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