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A new non-laminectomy model of the spinal cord injury: pressure impactor

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The influence of air pressure impact on rat spinal cord injuries is presented. In order to verify the non-laminectomy model of spinal cord injury, a professional device was designed. The device is based on pneumatic solution and gives the opportunity to carry out repeatable, unlimited, controlled experiments without the necessity of an extensive opening of the vertebral canal.

1. Introduction

Traumatic injuries to the spinal cord and their treatment are among the most serious challenges of the modern medicine. Each year, in the USA, about 10000 new cases of spinal cord injuries to humans are recorded and only slightly more than a half of the victims survive the injury, being paralysed till the end of their lives [1], [3]. Most of such injuries occur as a result of motorcycle accidents, suicide attempts, and injuries suffered due to amateurish practising of various sports [1], [3], [4]. It seems that in Poland, the main causes for the spinal cord injuries are jumps into the water, especially when done by people under the influence of alcohol and at sites where bathing is not allowed. The American data show that the average age of those affected by the injuries is 32 and the victims are predominantly men [3]. For these reasons, the economic and social consequences of the injury are enormous and come up to hundreds of thousand dollars per capita [1]–[3]. As yet, no effective methods of treating such injuries have been developed. In the acute phase of the injury, different neuroprotective drugs are applied. Whereas in the chronic one, attempts are made to prevent the development of glia scars and connective tissue scars at the injury site, to confine the necrosis zone, and, in the first place, to support the regeneration of damaged nerve fibres, the so-called long projection tracts [3]. However, to be able to compare the research results from different centres, a uniform model of the spine cord injury in laboratory animals needs to be developed. Such a model should possibly faithfully reconstruct the pathomechanizm of spinal cord injury in humans. With this end in view, in 1911, Allen et al. constructed a special device, the so-called *weight drop model*, which has been used successfully in various versions to the present day and called the *New York Impactor* [1], [3]. The extent of injury caused depends, among other things, on the weight dropped to the surface of spinal cord, as well as on the height it has been dropped from. Recently, researchers pay special attention to the device causing a vertebral dislocation of the spinal cord, i.e., causing a kind of a sudden local displacement of the spinal column in relation to its long axis with immediate effect of stretching nerve fibers [2]. Additional advantage of the device is the feasibility to cause the spinal cord injury without performing laminectomy as the latter requires conducting surgical procedure that is relatively difficult in technical terms and additionally exposes laboratory animals to prolonged general anaesthesia [3]. Moreover, in human patients, bone fragments are removed only when they are responsible for a lack of space inside the vertebral canal [2]–[4].

The design process of device affecting non-laminectomy model of spinal cord injury as well as the research with it are presented in this paper.

2. Construction of device

2.1. Project assumptions

At the beginning of the design process the following criteria for the device were formulated:

- the device should offer the possibilities of generating controlled, repeatable injuries to spine cord,
- the device should allow the changes in physical parameters of the air jet in order to generate wide range of injuries, i.e., from spinal cord concussion to its complete damage,
- the device should offer the possibility of artial impact,
- the minimization of production costs,
- a long-time failure-free work,
- a resistant and functional construction.

2.2. Project stages

Design process was preceded by precise analysis of functional demands in relation to physical possibility of the device realization. Several possible preliminary variants were designed. Finally, after engineer's and medical doctor's verification, the device based on air injection producing spinal cord injuries was accepted and the following steps were taken:

- selection of system elements,
- control system creation,
- design and power system creation,
- work out and creation of pneumatic system,
- experimental validation of device.

During the selection of device elements a quality accuracy was taken under consideration. It was connected with the demand for the precision being adequate for such experiments. Equipment had to generate impulses of compressed air injection which would exert pressure on spinal cord. Servicing should be intuitive and should allow initial parameters to be fast corrected.

In order to satisfy the above mentioned requirements, the control system based on numerical electronics has been applied which gives the opportunity to set up a valve starting time with the accuracy up to 0.1 s. The starting time could be programmed in a wide range, i.e., from 0.1 to 99 s, with 100% of impulse fulfilling. Control unit is presented in figure 1.

Fig. 1. Control unit of valve opening

One of the most difficult problems was proper valve selection. The majority of valves used in pneumatics work after receiving the input pressure of above 0.5 bar and they do not allow precise dosing during the opening time of 0.1 or 0.2 s, which is connected with elements inertia.

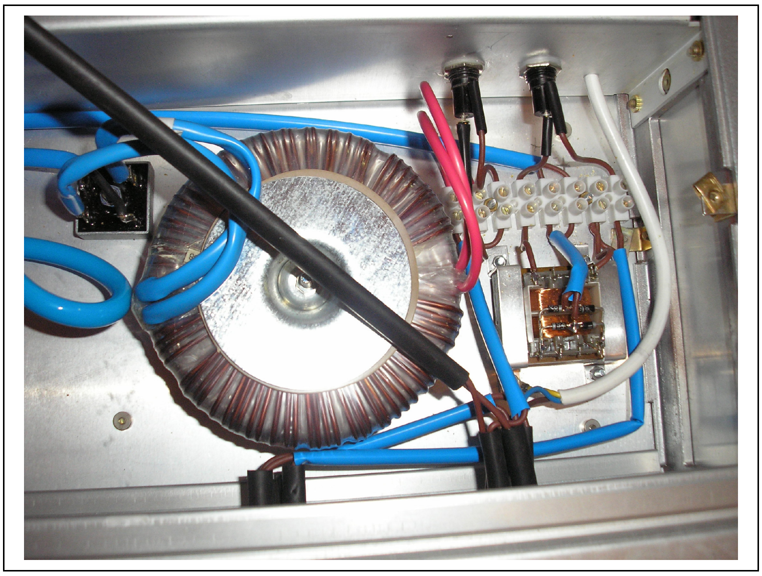

Fig. 2. Power system feeding electro-valve and numerical clock

Fig. 3. Compressor with reducer and pressure switch

Due to the above problems the sequence electromagnetic valve used in car gas installation was applied. The disadvantage of electromagnetic valve is high energy consumption during 100% fulfilling of liberation impulse. The energy absorption reaches 14 A. Because of these problems the construction of valve power control system was considered a necessity. The transformer and Gretz bridge were applied. The voltage from feeder is transmitted through power transistor steered by numerical clock to the input of injector. The power system is presented in figure 2.

The injector is fed with compressed air transmitted by compressor. At the compressor output the reducer which allows the pressure on electro-valve to be set with the precision approaching 0.2 bar is installed. The system of high pressure is protected by safety valve. The compressor is shown in figure 3.

Fig. 4. Stand with changeable tips

Because the diameter of rat's spinal cord is equal to 3 mm, the injector was placed in the stand offering the possibility of attaching changeable tips. The syringes with needles of different diameters were applied. In order to avoid the situations dangerous for users, the needles were permanently attached to syringes. The use stand is presented in figure 4.

3. Device test

The tests were carried out after creation of the prototype device. The experiment performed is presented in figure 5.

Fig. 5. The first experimental tests with the use of device

After the opening of the spinal canal, the device tip was put to the spinal cord. Then the impulse of compressed air caused nerve system injuries.

4. Conclusion

The device developed by our team allows a repeatable, fully controlled spinal cord injury to be caused without any extensive opening of the vertebral canal. Therefore, the model is easy to apply and the device itself is easy to operate. Another advantage of our model lies in developing an original set stabilizing the vertebral column so that the impact on the spinal cord surface is precise. It seems that our model can be applied successfully in both larger and small laboratory animals. This is especially important since in the case of "laminectomy spinal cord injuries", which anyway definitely prevail, the very loss of blood related to the surgical procedure results in some losses of small laboratory animals subjected to surgical intervention. This was also the reason for developing specific models of the spinal cord injuries, especially in mice, for instance, through the cord compression by means of "silicon microtube" introduced for a fixed period of time through a tiny trepanation opening on the spinal cord surface. The long-term objective of the research conducted by our team is to develop an effective method of repairing the spinal cord in laboratory animals with the use of properly modified stem cells applied in the injury site. We did not cause any extensive injuries, including cutting off a certain fragment of the spinal cord, since our main objective was to reconstruct faithfully the human injury which occurs most frequently, i.e., the one with only partial spinal cord damage. The device is one of the elements of laboratory infrastructure to the experiments ran on rat spinal cord regeneration at the Medical

University of Silesia. The authors hope that in near future, the experiences acquired due to the experiments ran on animals will result in the invention of successful treatment methods for people with nerveous system injuries.

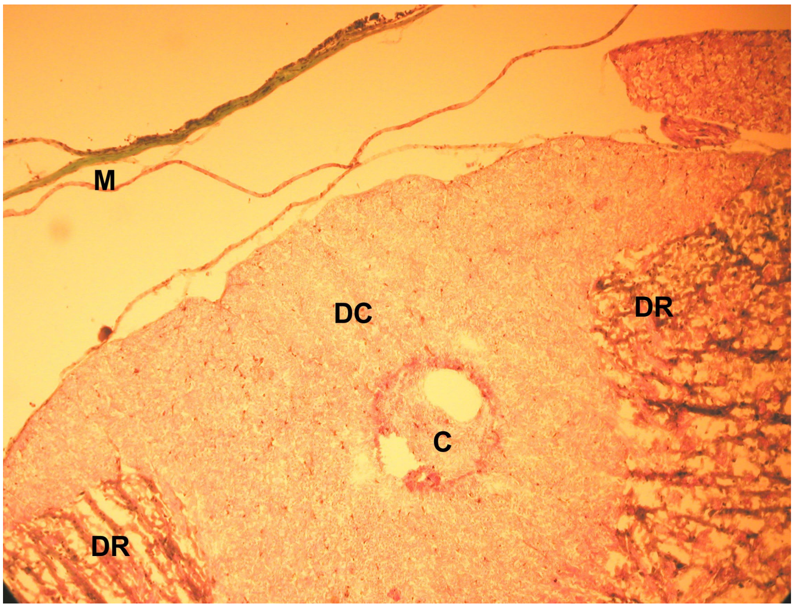

Fig. 6. Microphotography showing typical microcyst induced by pressure impactor, located in the white matter of dorsal column of the spinal cord. Masson trichrome staining. Original magnification 200×. M – meninges, DC – dorsal columns, DR – dorsal roots, C – cyst

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