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An in vitro analysis of the size and shape of cryolesions for facet joint denervation

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ABSTRACT

Objectives: Lumbar facet joint syndrome (LFJS) is the cause of lower back pain in 15–54% of the patients. Clinical studies of cryotherapy for LFJS have reported promising outcomes. However, few studies have focused on the technical aspects of cryoneurolysis for LFJS.

The aim of the study was to determine the size and shape of cryolesions in vitro and to determine how they are affected by the duration of freezing, size of the cryoprobe and distance and angulation to an osseous boundary layer.

Materials and methods: Two different cryolesion generators were used. Cryolesions were generated in tempered physiologic NaCl solution in the vicinity of an osseous surface. The size of the cryoprobes, duration of freezing, distance to the bone surface and angulation of the probe were studied. Cryolesions were recorded with a video camera during their emergence. Images at distinct time points were analysed using digital image processing software.

Results: The probe size, the system in use and the duration of the freezing cycle were the main determinants for the size of the cryolesion. The vicinity of the osseous boundary resulted in a modest increase in the size of the cryolesion. Angulation of the cryoprobe towards the osseous boundary is of minor importance for the size of the contact area to the nerve.

Conclusion: For cryoneurolysis of LFJS, duration of freezing, temperature and probe size are the main determinants of lesion size and thus the probability of success of the procedure. A tangential approach of the probe is not essential.

1. Introduction

Lumbar facet joint syndrome (LFJS) is the cause of pain in 15–54% of patients with low back pain. LFJS was first described by Ghormly in 1933 [1]. Clinically, LFSJ is characterised by a deep dull pain in the lower back, which often radiates into the leg and may be difficult to localise. The pattern of radiation is not radicular unless there is a concomitant nerve root compression. Often, the pain worsens with physical strain and can be provoked by lateral bending and/or hyperextension. Pain can sometimes be elicited by pressure on the affected joint, and neurologic exams are usually normal.

Facet joints contain free and encapsulated nerve endings as well as nerves containing substance P and calcitonin gene-related peptides [2,3]. Facet joint capsules contain low threshold mechanoreceptors, mechanically sensitive nociceptors and silent nociceptors [4,5]. Biomechanical studies have shown that facet joint capsules can undergo high strain during spine loading [6–8].

Treatment involves conservative therapy with physiotherapeutic exercise programs, behavioural therapy and medical therapy. Interventional therapy includes facet joint injections, particularly intraarticular steroid injections. Because these therapies do not often demonstrate lasting effects, strategies involving denervation of the joint, such as radiofrequency denervation, have been proposed.

Cryoneurolysis can be utilised as an alternative technique for facet joint denervation.

Cryotherapy has been described as a denervation technique in a variety of neuropathic and nociceptive pain conditions [9]. There are a number of studies regarding cryotherapy for LFJS [10–14], which describe favourable clinical outcomes. However, few studies

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have focused on the technical aspects of cryoneurolysis for LFJS [15].

The aim of this study was to determine the size and shape of cryolesions in vitro and to determine how they are influenced by the duration of the freezing cycle, size of the cryoprobe and distance and angulation to a boundary layer such as osseous tissue.

2. Material and methods

Institutional Review Board (IRB) approval was not required as no human or animal subjects or patients were involved.

2.1. Experimental environment

The cryolysis experiments were conducted in a glass container measuring $40 \times 30 \times 25$ cm. The container was filled with 0.9% physiological sodium chloride solution. Cryolesions were formed on a $5 \times 3 \times 2$ cm piece of sheep bone. We used a thermostat to warm the NaCl solution to 37 °C to maintain physiologically relevant conditions before each cryolysis cycle to maximise the accuracy of the experiment. However, after every warming cycle, a 2–3 min pause was taken to prevent the movement of the water masses from affecting cryolysis.

2.2. Platform

A special platform was constructed to store the glass container in the exact same position so that the same perspective could be used during video recording of the entire experiment. In addition to holding the glass container in the same place, this also allowed the thermostat to be attached to the wall of the container and allowed the cryoprobe to be attached to a micromanipulator above the container. The micromanipulator allowed the probe to be accurately moved up and down while measuring the distance between the probe and the osseous boundary (Fig. 1). Distances of 0, 1 and 3 mm were studied.

2.3. Cryolesion generators

Two different cryolesion generators were used. One generator used liquid nitrogen as a source for freezing (Kryotherapiegerät "freyja", Tricumed Medizintechnik GmbH, Kiel, Germany). This generator worked with 2 different probes (1.4 mm and 2.4 mm diameter) at temperatures of −50, −70 and −150 °C. The other generator was a carbon dioxide generator (Lloyd Neurostat SL2000, Inomed GmbH, Teningen, Germany), which was operated with 1.4 and 2.9 mm probes at flows of 6, 10 and 20 l/m.

2.4. Video recording

Video recording was performed with a Panasonic NV – GS 320EG-S camera and Panasonic SweetMovieLife 1.0E/MotionDV Studio 5.6E LE software for DV. Prior to each single experimental setup, an image of the probe tip and bone before cryolysis was recorded. Each single cryolysis was repeated 3 times with images recorded at predefined times. This approach allowed for the same perspective to be maintained during a series of images for a certain experimental setup, which was vital for the analysis of every series of 3 cryolysis images and the corresponding images without cryolesions (blank image).

2.5. Processing of data and calculation of area

The area of the cryolesion was determined after the entire series of images was recorded using an image editing program (Adobe Photoshop CS3). The area of the cryoprobe was first marked on a blank image, and a scale was created using the exact diameter of the probe in millimetres so that the program could recalculate the results from pixels to millimetres. The areas of the probe and cryolesion in the following 3 images in each series were calculated. By subtracting the area of the probe on the "blank image" from the area of the cryolesion on the 3 experimental images, the true area of the cryolesion was calculated. Assuming a spherical lesion in this model, a 10 mm^2 corresponds to a lesion diameter of 4.1 mm. The values for the single measurements rarely diverged for more than 10%. For every series, an average of the 3 values was calculated, which represented the area of the cryolesion for that particular experimental setup. From the area of the cryoprobe theoretically a lesion volume could have been calculated. As not the absolute value of the lesion volume was of importance, but in which way the lesion size was affected by certain parameters, we rather chose only to present the raw data of our measurements.

2.6. Data analysis

The last step in analysing the results was to structure the recorded results according to the factor being studied. Five groups were created for each of the factors in the original study design. This allowed for an easier comparison of the results. Extra tables were drawn, which helped to identify the tendencies in which each of the factors influenced the size and shape of the lesion.

3. Results

3.1. Temperature

The temperature of the cryolesion generator had the greatest impact on the size of the cryolesions. On average, decreasing the temperature of the liquid nitrogen generator from −50 to −70 °C doubled the size of the lesion. A further decrease in temperature from −70 to −150 °C resulted in a 500–1000% increase in lesion size. Similar tendencies were observed for the carbon dioxide generator, although the increase in lesion size was smaller. Increasing the flow from 6 to 10 l/m resulted in an increase in lesion size of around 20%. However, increasing the flow from 10 to 20 l/m and using the 1.4 mm probe resulted in some unexpected problems, which decreased the size of the cryolesion. After verifying the accuracy of the experimental setup, we could not find any errors. Therefore, we concluded that the unexpected results resulted from a technical malfunction of the probe. Performing the same experiment with the 2.9 mm probe and increasing the flow from "low" to "high" resulted in a 100% increase in the size of the cryolesion. Functioning at a flow of 6 l/m was not possible for the 2.9 mm probe (Tables 1a and 1b).

3.2. Duration of freezing

Freezing was performed in cycles of 30, 60 and 120 s. The recorded results for the two cryolesion generators showed the same tendencies but differed in the degree to which the size of the cryolesion increased. Using the liquid nitrogen generator, increasing the duration from 30 to 120 s resulted in an increase of 61% in the size of the cryolesion.

3.3. Size of the cryoprobe

The size of the probe was a main factor that influenced the size of the cryolesion. Under the same conditions, the lesion size increased 112% for the liquid nitrogen generator when the larger diameter probe was used. With the carbon dioxide generator, using the larger probe (2.9 mm) resulted in an increase in the lesion size of 400% (Table 2).