Abstract: We examined the anatomical connections of trigeminal neurons between the trigeminal subnuclei interpolaris/caudalis (Vi/Vc) transition and caudal subnucleus caudalis/upper cervical dorsal horn (Vc/C1,2) zones in rats, using the fluorogold (FG) retrograde tracing method combined with Fos expression, a marker of neuronal activation, following temporomandibular joint (TMJ) inflammation. The head withdrawal threshold was also measured in rats 3 days after complete Freund's adjuvant (CFA)-induced TMJ inflammation. FG was injected into the Vi/Vc transition zone and retrogradely labeled FG-positive cells were observed in the Vc/C1,2 region. Numerous Fos protein-expressing cells were present both in the Vi/Vc transition zone and in the laminated Vc/C1,2 zone. A population of cells was double-labeled with Fos and FG in the Vc/C1,2 zone. Fos/FG cells were only observed in the deep laminae of the Vc/C1,2 zone. These findings suggest that Vi/Vc transition zone activity is modulated by activation of the caudal laminated zone after orofacial tissue injury. (J. Oral Sci. 47, 65-69, 2005)

Keywords: temporomandibular joint (TMJ) inflammation; Fos protein-LI cell; Fluorogold (FG); brainstem; trigeminal spinal nucleus.

Introduction

It has been reported that trigeminal nociceptive information is sent to the nucleus caudalis of the trigeminal spinal nucleus and upper cervical cord (1-3). Following peripheral inflammation, Fos studies have revealed that two peaks of Fos protein-like immunoreactive cells (Fos protein-LI cells) are expressed; one in the transition zone between the trigeminal spinal nucleus interpolaris and caudalis (Vi/Vc zone), and one in the caudal laminated region between the caudalis and upper cervical dorsal horn (Vc/C1,2 zone) (4). Further studies have suggested that these two areas functionally differ in the processing of inflammation-induced nociception in the trigeminal region. However, it is unknown whether nociceptive neurons that are activated by peripheral inflammation, are anatomically connected within these two regions. In the present study, we examined the anatomical relationship between nociceptive neurons in the Vi/Vc and Vc/C1,2 zones through fluorogold (FG) retrograde tracing combined with Fos expression following temporomandibular joint (TMJ) inflammation.
Materials and Methods

The present experiment was approved by the Animal Experimental Committee of Nihon University School of Dentistry and animals were treated according to the guidelines of the International Association for the Study of Pain (5). Adult male Sprague-Dawley rats (260-320 g) were used for all experiments.

Rats were anesthetized with pentobarbital Na (50 mg/kg, i.p.) and Complete Freund’s adjuvant (CFA, 0.05 ml) was injected into the left side of the TMJ capsule through the facial skin. CFA was suspended in an oil/saline (1:1) emulsion. Three days after CFA injection, rats were tested for mechanical hyperalgesia. Ten rats that had limited access to a 10% sucrose solution (100 ml/kg/day for 1 week) were used for behavioral study. The animals were able to drink the sucrose solution through a hole in the front panel of the plastic cage. They were trained to continue drinking sucrose solution during noxious mechanical stimulation of the lateral face. The mechanical stimulation was applied with von-Frey monofilaments through a small hole (1 cm in diameter) in the lateral wall of the plastic cage. The mechanical stimulation was applied to the lateral face 2 mm below the posterior edge of the zygomatic arc. The rats showed normal weight gain during the training session. The training was considered to be successful when the rats were able to continue drinking sucrose solution for 10 min without escaping from 36g mechanical stimuli. At the end of the training period, injection was performed (CFA TMJ group; n = 5, naive group; n = 5). Three days after injection, all animals were tested with von-Frey hairs. Each hair was applied twice at intervals of 5 s and the two values were averaged. The bending force of the first hair to evoke an escape response was designated as the escape threshold intensity.

Fifteen rats were used for Fos and Fluorogold (FG) tracing experiments. Rats were anesthetized with pentobarbital Na (50 mg/kg, i.p.) and CFA was injected into the left TMJ. Animals were then fixed on a stereotaxic frame, the Vi/Vc zone was exposed and FG was injected to evoke an escape response was designated as the escape threshold intensity. Fifteen rats were used for Fos and Fluorogold (FG) tracing experiments. Rats were anesthetized with pentobarbital Na (50 mg/kg, i.p.) and CFA was injected into the left TMJ. Animals were then fixed on a stereotaxic frame, the Vi/Vc zone was exposed and FG was injected into the left side of the TMJ capsule through the facial skin. CFA was suspended in an oil/saline (1:1) emulsion. Three days after CFA injection, rats were tested for mechanical hyperalgesia. Ten rats that had limited access to a 10% sucrose solution (100 ml/kg/day for 1 week) were used for behavioral study. The animals were able to drink the sucrose solution through a hole in the front panel of the plastic cage. They were trained to continue drinking sucrose solution during noxious mechanical stimulation of the lateral face. The mechanical stimulation was applied with von-Frey monofilaments through a small hole (1 cm in diameter) in the lateral wall of the plastic cage. The mechanical stimulation was applied to the lateral face 2 mm below the posterior edge of the zygomatic arc. The rats showed normal weight gain during the training session. The training was considered to be successful when the rats were able to continue drinking sucrose solution for 10 min without escaping from 36g mechanical stimuli. At the end of the training period, injection was performed (CFA TMJ group; n = 5, naive group; n = 5). Three days after injection, all animals were tested with von-Frey hairs. Each hair was applied twice at intervals of 5 s and the two values were averaged. The bending force of the first hair to evoke an escape response was designated as the escape threshold intensity.

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head withdrawal threshold and analyzed immunohistochemical data at 3 days after CFA injection into the TMJ.

**Results**

CFA injection into the TMJ significantly decreased the head withdrawal threshold on the injected side (Fig.1), thus suggesting the development of mechanical allodynia/hyperalgesia. Figure 2 illustrates the site of FG injection in the Vi/Vc transition zone (Fig. 2A). Retrogradely labeled FG-positive cells were observed in the Vc/C1,2 region (Fig. 2C-F), indicating the intranuclear connection between the Vi/Vc and Vc/C1,2 zones. Consistent with previous studies, numerous Fos protein-LI cells were present in both the Vi/Vc transition zone and the laminated Vc/C1,2 zone (Fig. 3A). Many neurons in the deep and superficial laminae exhibited Fos protein immunoreactivity after TMJ inflammation. There were also cells that were double-labeled with Fos and FG (Fos/FG cells) in the Vc/C1,2 zone (Fig. 2D). Most of the Fos/FG cells had spindle-shaped or multipolar soma (Fig. 2C-F). Although Fos-positive cells were observed in the superficial and deep laminae of the medullary dorsal horn, Fos/FG cells were only observed in the deep laminae of the Vc/C1,2 zone (Fig. 3A). Double-labeled cells appeared to be present in all segments of the Vc/C1,2 zone (Fig. 3B).

**Discussion**

It has been reported that Fos protein is induced in a large number of cells in the trigeminal spinal nucleus, including the Vi/Vc transition zone and laminated Vc/C1,2 regions,
following CFA injection into the TMJ (4,6,7). Fos protein-LI cells are distributed into two populations; one in the Vi/Vc zone and one in the Vc/C1,2 zone. The two populations of Fos protein-LI cells may play different roles in trigeminal nociceptive processing after orofacial tissue injury. Hirata et al. (8) reported that neurons in these two zones differentially respond to morphine. Neurons in the Vi/Vc transition zone may be activated after injury in order to participate in pain modulation. Previous studies have reported that there are neuronal networks within the trigeminal spinal nucleus or the cervical cord that contribute to control of trigeminal nociception (9,10-13). However, the functional connection within the trigeminal spinal nucleus is unknown.

The present study demonstrates that neurons in the Vc/C1,2 zone are activated by TMJ inflammation and directly project to the Vi/Vc zone. Our results also indicate that Vc/C1,2-Vi/Vc projection originates mainly from neurons located in the deep laminae of the Vc/C1,2 zone. This is consistent with previous suggestions that the ascending pathway from Vc/C1,2 exerts a modulatory effect on the activity of neurons in the more rostral subnuclei of the trigeminal brain stem nucleus (14). More recently, Meng et al. (15) showed that topical application of glutamate and morphine onto the Vc/C1 region altered the evoked activity of ~30% of corneal units tested in the Vi/Vc. Both facilitatory and inhibitory effects were noted. These findings suggest that transition zone activity is modulated by activation of the caudal laminated zone. The Vi/Vc transition zone has been suggested to play a unique role in trigeminal responses to orofacial injury (16), but the region, particularly the ventral portion of the transition zone, generally does not receive direct primary afferent input from the orofacial region.

The present results indicate that the information from the injured TMJ is specifically relayed to the Vi/Vc transition zone via the caudal laminated Vc/C1,2 zone. This pathway is activated by TMJ injury and may contribute to altered central processing after injury.

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