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The anatomical structure of the stellate ganglion in the European badger (*Meles meles*)

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Abstract
The stellate ganglion belongs to the sympathetic part of the autonomic nervous system. It responds to signals from the brain to the organs in the chest, including the heart, whose function it regulates. In this study, an analysis of the normal anatomy of the stellate ganglion in the European badger was presented. The research involved 6 male specimens, 3 female specimens, and 1 specimen with undetermined sex. Dissection was performed to remove the skin and muscles of the thorax, as well as parts of the ribs and lungs. The shape, topographical location, dimensions, and the ganglia constituting the structure of interest were analyzed. The results were compared with studies conducted on other animal species. However, these studies are preliminary and require further expansion with a larger group of specimens. They provide a basis for further development of the normal and comparative anatomy of the European badger.

Running title: The stellate ganglion of the European badger

Keywords: European badger, autonomic nervous system, stellate ganglion

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Introduction

The nervous system can be divided into the somatic and autonomic systems. The autonomic system is further subdivided into the sympathetic and parasympathetic components. These systems act on organs in an antagonistic manner—the sympathetic system is responsible for the “fight or flight” response, while the parasympathetic system calms the body and stimulates digestive processes [1,2].

Anatomically, the sympathetic part includes the paired sympathetic trunk (*truncus sympathicus*), which connects with the vagus nerve (*nervus vagus*) at the cervical segment, forming the vagosympathetic trunk (*truncus vagosympathicus*). At this level, it gives rise to three cervical ganglia: cranial, middle, and caudal (*ganglion cervicale craniale, medium, caudale*). The caudal ganglion connects with the first thoracic ganglia to form the cervicothoracic/stellate ganglion (*ganglion cervicothoracicum/stellatum*), located between the transverse process of the 7th cervical vertebra and the neck of the 1st rib, dorsally relative to the subclavian artery [3]. This ganglion is one of the main sites of sympathetic fiber crossover, which then forms branches that travel to the thoracic organs, regulating their function. Additionally, it connects with peripheral nerves of the brachial plexus via postganglionic fibers, thus regulating the activity of, among other things, sweat and sebaceous glands in the forelimb.

The aforementioned fibers contribute to the formation of structures such as the subclavian loop (*ansa subclavia*), subclavian plexus (*plexus subclavius*), cardiac nerves (*nervi cardiaci*), and branches involved in the creation of the cardiac plexus (*plexus cardiacus*), the spinal nerve (*nervus vertebralis*), and the spinal plexus (*plexus vertebralis*) [1,2].

To date, the anatomy of the stellate ganglion has been studied in many animal species. These studies have provided extensive data on this structure, including its shape, size (length, width), topographical location, and the number of branches emerging from the ganglion. It has also been possible to determine the components that form the cervicothoracic ganglion in specific cases (which cervical and thoracic ganglia it comprises). Numerous anatomical differences have been demonstrated among different species, different individuals of the same species, and even between the right and left sides of a single individual. These variations generally pertain to shape (star-shaped, elongated, oval) and location.

The aim of our study is a morphological analysis of the stellate ganglion in European badgers (*Meles meles*), considering the aforementioned characteristics, which will serve as a basis for further comparison of this structure among closely and distantly related species. Additionally, we aim to determine whether there are correlations between these characteristics and the sex and side of the body on which the ganglion is located (right/left).

Materials and methods

The research material consisted of 3 female badgers and 6 male badgers. One specimen did not have the body caudal to the diaphragm, so its sex could not be determined. In total, 10 specimens were analyzed. No animal was euthanized specifically for the purpose of this study. The specimens were found in forests in Poland. The analyzed specimens did not show signs of decomposition, which allowed for the conduct of the study.

The collected specimens were preserved by placing them in a basin with a 10% formalin solution. However, this procedure was preceded by an incision of the abdominal wall and opening of the thoracic cavity to allow formalin to preserve the internal organs as quickly as possible. In the case of 5 specimens, before they were placed in the preservative solution, liquid red latex LBS 3060 was introduced into the aorta to better trace the relationship of the nervous system to the arterial blood vessels.

The specimens were stored in a 10% formalin solution for a minimum of 4 weeks. The study was conducted using macroscopic preparation with a scalpel and micro forceps. To access the thoracic cavity and determine the position of the ganglion relative to the ribs, ribs were removed. Finally, portions of the lungs were cut away, and the pleura, adipose tissue, and individual muscle fibers were removed, which allowed for the isolation of the stellate ganglion. Measurements were made using an electronic caliper with an accuracy of 0.1 mm. Additionally, photographic and tabular documentation was created, and the descriptive part utilized the nomenclature from the Nomina Anatomica Veterinaria [4].

Results

The cervicothoracic ganglion (**Fig. 1, 2**) in the studied European badgers (*Meles meles*) arises from the fusion of three ganglia: the caudal cervical ganglion (*ganglion cervicale caudale*), the first thoracic ganglion (*ganglion thoracicum I*), and the second thoracic ganglion (*ganglion thoracicum II*). This was observed in all cases.

The stellate ganglion is located laterally to the trachea, on the lateral surface of the longus colli muscle (*musculus longus colli*), near the vertebral and subclavian arteries (*aorta vertebralis et subclavia*). It is found at the level of the 1st rib (2 cases on the left side, in specimens of different sexes), between the 1st and 2nd ribs (12 cases; 5 on the left side and 7 on the right), and at the level of the 2nd rib (6 cases; 3 on each side of the body).

Considering the location of the stellate ganglion relative to the body, it can be stated that its position was the same on both sides in 6 specimens, while in 4 specimens, it differed by a few millimeters.

Regarding the shape of the ganglion, it was star-shaped in 12 cases, with similar length and width, elongated in 6 cases, and irregular or oval in 2 cases.

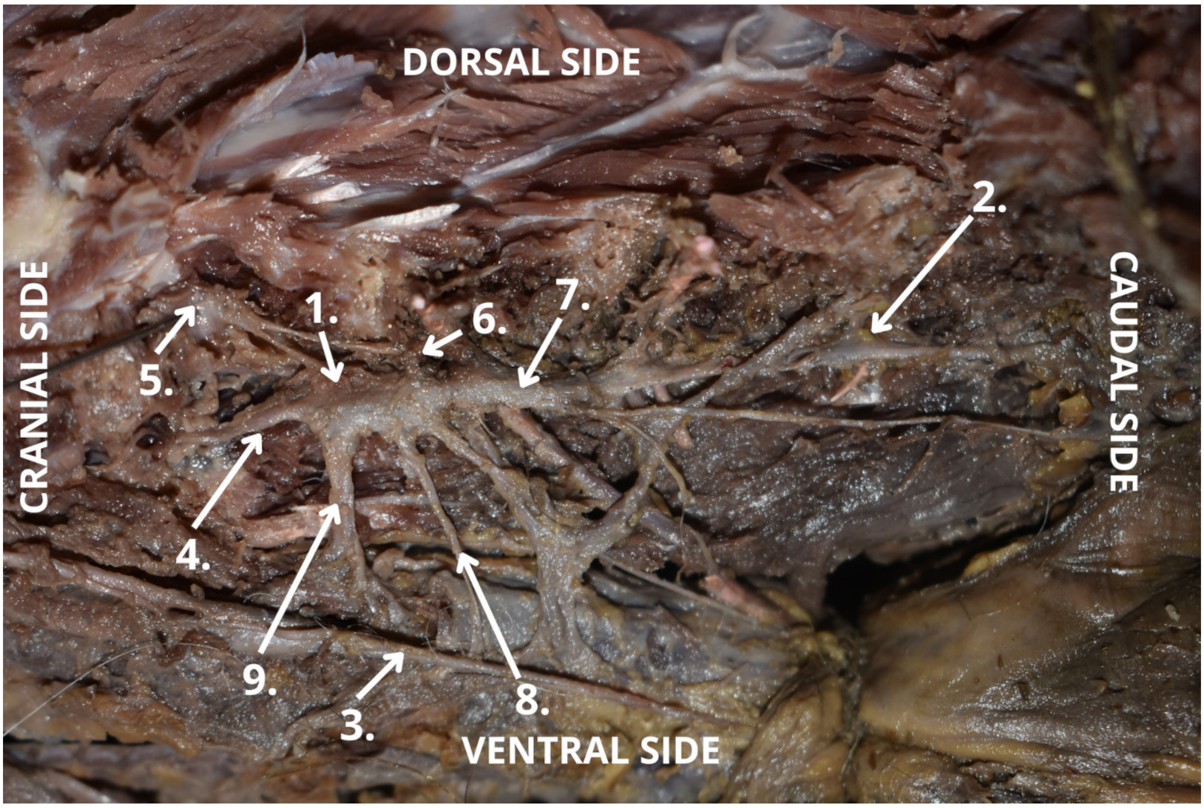

FIGURE 1 stellate ganglion of the badger – left side. 1 – stellate ganglion. 2 – sympathetic trunk. 3 – vagus nerve. 4 – vertebral nerve. 5 – branch connecting to Th1. 6 – branch connecting to Th2. 7 – third thoracic ganglion. 8 – caudal branch of the subclavian loop. 9 – cranial branch of the subclavian loop

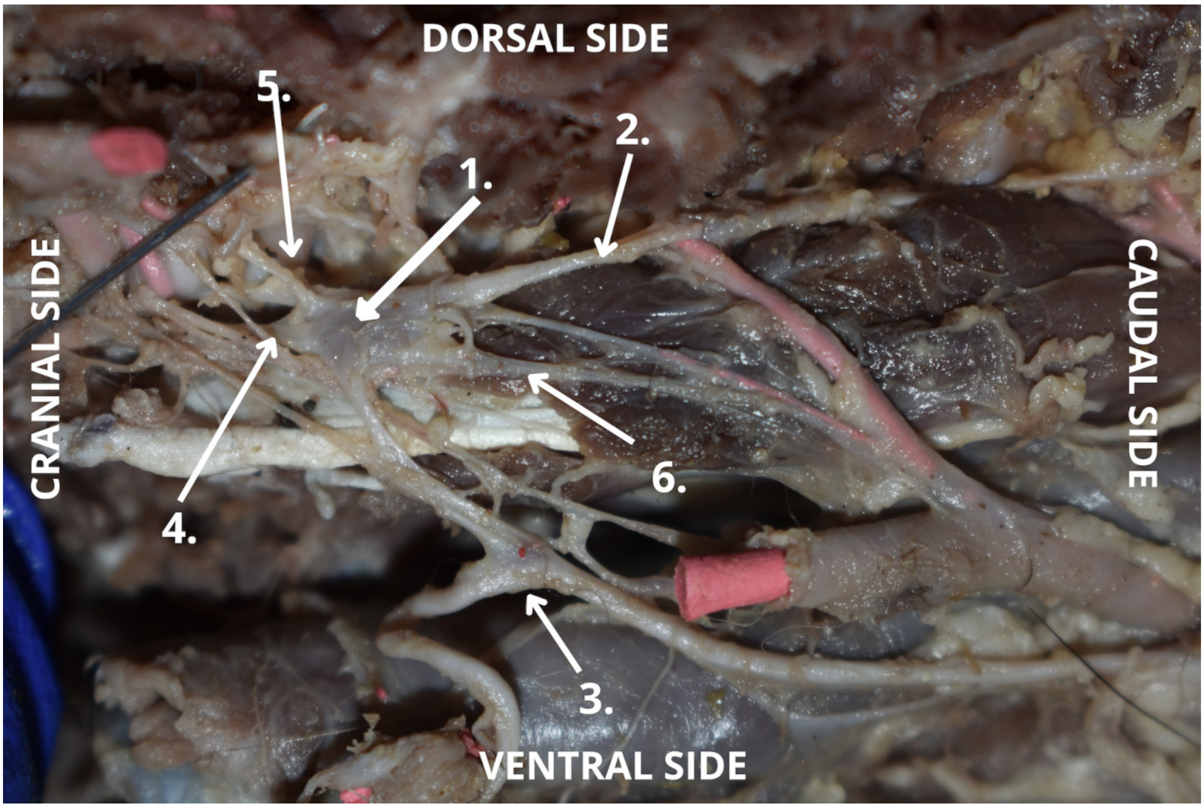

FIGURE 2 Stellate ganglion of the badger – left side. 1 **–** stellate ganglion. 2 – sympathetic trunk. 3 – vagus nerve. 4 – spinal nerve. 5 – connecting branch to Th1. 6 – cardiac branch

TABLE 1 Dimensions and location of the stellate ganglion in the examined subjects

No.	SEX	LEFT SIDE			RIGHT SIDE		
		LENGHT [mm]	WIDTH [mm]	LOCATION	LENGHT [mm]	WIDTH [mm]	LOCATION
1	F	7,0	3,3	On the 1st rib	11,8	4,1	Between 1st and 2nd ribs
2	M	6,6	6,4	Between 1st and 2nd ribs	6,4	4,6	Between 1st and 2nd ribs
3	M	8,9	3,0	Between the 1st and 2nd ribs	4,3	3,7	On the 2nd rib
4	F	6,9	6,0	Between the 1st and 2nd ribs	10,4	5,4	Between 1st and 2nd ribs
5	M	8,0	7,4	Between 1st and 2nd ribs	10,8	4,3	Between 1st and 2nd ribs
6	-	6,3	2,5	On the 2nd rib	6,2	2,7	On the 2nd rib
7	M	5,8	6,1	On the 2nd rib	7,7	3,2	On the 2nd rib
8	M	8,3	6,2	On the 1st rib	7,9	7,3	Between 1st and 2nd ribs
9	F	7,2	5,4	On the 2nd rib	7,3	4,7	Between 1st and 2nd ribs
10	M	10,7	5,9	Between 1st and 2nd ribs	5,2	4,7	Between 1st and 2nd ribs

The ganglion most commonly assumed an elongated (irregular) shape on the right side (6 cases) and a star-shaped form on the left side (5 cases).

The average length was 7.57 mm on the left side and 7.8 mm on the right side, while the average width was 5.22 mm on the left and 4.47 mm on the right. Exact measurements are presented in **table 1**.

It is difficult to definitively determine whether there is a correlation between features such as shape, size, or location of the ganglion and sex, as only three females were used in the study, which differ from each other in these parameters.

In all the cases we examined, the cervicothoracic ganglion gave off the same branches, which are the following structures:

1. Spinal Nerve (*nervus vertebralis*): Positioned cranially, it runs along the vertebral artery and vein. It enters the transverse foramen of the sixth cervical vertebra with the artery and continues as the spinal plexus along this artery.
2. Subclavian Loop (*ansa subclavia*): This consists of cranial and caudal branches that encircle the subclavian artery and join at the middle cervical ganglion on its medial surface. It also contributes to the formation of the subclavian plexus.
3. Branches Connecting to the Vagus Nerve (*rami communicantes cum nervi vagi*): Located ventrally, these branches direct slightly towards the heart.
4. Cardiac Branch (*ramus cardiacus*): Positioned more caudally relative to the vagus nerve, it also directs towards the heart, where it joins fibers from other cervical ganglia to form the cardiac plexus. The fact that the heart is not centrally located in the thoracic cavity is reflected in the length and course of these branches. Specifically, those originating from the left ganglion are shorter than those from the right, due to a less complicated path.
5. Sympathetic Trunk (*truncus sympathicus*): Positioned most caudally among all the branches, it runs parallel to the spine. In further body segments, it forms additional sympathetic ganglia.
6. Branches Connecting to Thoracic Spinal Nerves Th1 and Th2 (*rami communicantes cum Th1 et Th2*): The ganglion connects to the spinal cord via preganglionic fibers.

Discussion

Authors who have previously studied the anatomy of the cervicothoracic ganglion in other animals have reported differences in its structure, connections, location, or shape, which partially align with our observations. A similar structure to that in badgers was observed by Klećkowska [3] and by Kabak [5]; in all these cases, the ganglion consisted of the caudal cervical ganglion and the first two thoracic ganglia. Grzeczka and Frąckowiak [6], in their studies on domestic cats, found that the ganglion of interest additionally included the third thoracic ganglion, which distinguishes it from the stellate ganglion in badgers, where the third thoracic ganglion was a separate structure. This is interesting because cats belong to the order Carnivora (suborder Feliformia), while badgers belong to the order Carnivora as well but the suborder Caniformia, making cats evolutionarily closer to badgers than to roe deer (**Tab. 2**).

Regarding the shape of the stellate ganglion, significant interspecies differences can be observed. In pigs, a triangular shape is most typical, while cats have been observed to have oval, elongated, or irregular star-shaped ganglia. In roe deer, in addition to the shapes mentioned above, an "L"-shaped ganglion has also been described [3,5]. Considering the shape of the ganglion in badgers, it is similar to that in cats—usually star-shaped or elongated [6]. This is interesting because the components of the ganglion in these animals differ.

In badgers, the cervicothoracic ganglion is most commonly located in the space between the first and second ribs. The same location has been studied in dogs by M.M.A. Abumandour et al. [7]. In 9-week-old pig fetuses, it was located at the cranial edge of the first rib [3]. As described by Klećkowska et al. [8], in newborn Persian cats, there is considerable variation in the location of the ganglion: above the first rib, at the level of the first rib, in the space between the first and second ribs, or even between the first and third ribs. Interestingly, in European cats [6], in ¾ of the cases, the ganglion was located in the space between the first two ribs.

The cervicothoracic ganglion mediates the transmission of impulses from higher centers of the nervous system [1]. Lajos Angyan et al. [9] observed in their studies on cats that stimulation of the dorsal nucleus of the thalamus affects an increase in blood pressure, which is mediated by the ganglion we studied.

Chinese researchers performed stellate ganglion blockade in male rats, inducing diabetes and an ischemic stroke model through diet and occlusion of the middle cerebral artery. It was found that this blockade reduced inflammation and water content in the brain, as well as improved neurological function [10].

In a study involving 30 dogs that survived a myocardial infarction and subsequently suffered from ventricular arrhythmias [11], it was noted that increased activity of the stellate ganglion exacerbates ventricular arrhythmias. Additionally, it was found that spinal cord stimulation near the stellate ganglion could alleviate or entirely prevent such arrhythmias after acute myocardial infarctions.

Referring to human medicine, it is worth mentioning that from 2016 to 2018, the Duke Neurocardiology Department attempted to treat ventricular tachycardia (VT) and ventricular fibrillation (VF) using bilateral stellate ganglion blockade (SGB). The study included 20 patients resistant to pharmacological treatment for both conditions. This procedure proved to be nearly non-invasive and effective—within 24 hours, reduced arrhythmia burden was observed in the patients. These results provide a basis for further research, which may in the future enable large-scale treatment of severe cases of VT and VF [12].

TABLE 2 Comparison of the shape and components of the stellate ganglion in selected species

SPECIES	THORACIC GANGLIA INCLUDED	SHAPE	SOURCE
Dog	Th1 and Th2	Elongated or fusiform	M.M.A. Abumandour et al. (2021)
Domestic Cat	Th1, Th2 and sometimes Th3	Star-shaped or round	Grzaczka and Frąckowiak (2021)
Persian Cat	Th1 and Th2	Oval, elongated, or triangular	Klećkowska et al. (2001)
American Staffordshire Terrier Fetuses	Th1, Th2 and Th3	Oval, elongated, or fusiform	Klećkowska et al. (2007)
European Roe Deer	Th1 and Th2	Round, fusiform, or triangular	Kabak (2019)
9-Week-Old Pig Fetuses	Th1 and Th2	Fusiform, triangular, or oval	Klećkowska et al. (2003)

Interestingly, due to the SARS-CoV-2 pandemic, there has also been focus on the impact of stellate ganglion blockade on alleviating post-COVID symptoms (commonly referred to as Long COVID), such as excessive fatigue, brain fog, or taste disturbances. Bilateral blockade was performed in two patients, and in both cases, positive results were obtained—immediately after the procedure, the women regained mental clarity and began to perceive taste stimuli again [13].

This highlights the importance of understanding the anatomy (location, number, and type of branches) of the cervicothoracic ganglion, as this knowledge allows for determining the impact of damage to this structure on associated internal organs and can enable the treatment of various conditions in both humans and animals.

Conclusions

It has been shown that the stellate ganglion in European badgers consists of three components – the caudal cervical ganglion and the first two thoracic ganglia. Distinct differences were noted in the shape and size of this structure on the right and left sides of the animal, as well as among individuals. Bilateral ganglia often had different locations; however, relative to the ribs, they were always found within the range between the first and second ribs. No differences were observed regarding the branches leaving the described ganglion – they were always the same number and of similar length and thickness.

This work is a preliminary study aimed at comparing the analogies of these parameters with the results obtained by other authors concerning the cervicothoracic ganglion in different species. Although this study should be verified through repetition with a larger group of animals, it serves as a basis for expanding knowledge on the normal anatomy of this structure.

Ethical approval
The conducted research is not related to either human or animal use.

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Conflict of interest statement
The authors declare no conflict of interest.

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