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Fine Structure of Scorpion Pectines for Odor Capture

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Abstract

The paper revealed the fine structure of the scorpion (*Mesobuthus martensii*) pectines and showed how the fine structure of the pecten influences odor flow. The first step of our investigation was to prove that scorpion pectines work as olfactory and this was done via experiments utilizing paraffin coverage. Subsequently, the location, morphology, section structure, and arrangement of the pectines were studied via stereomicroscopy and Scanning Electron Microscopy (SEM). The fine structure of pecten comprises a comb-like structure with 24-30 knife-like teeth and thousands of micron bowl-like pecten sensilla in staggered arrangement on the surface of the tooth. Computational Fluid Dynamics (CFD) was applied to predict odor flow around the pecten via the relevant Reynolds numbers. The comb-like structure amplified the odor flow velocity similar to an amplifier, transporting the odor flow of increased velocity to the micron pecten sensilla, improving transport efficiency of the odor flow. The staggered arrangement of the pecten sensilla generated a vortex, improving contact duration between pecten sensilla and odorant molecules. Thus, the pecten fine structure was likely acting as an effective comb with non-smooth teeth for the transport and capture of odorant molecules.

Keywords: scorpion pectines, fluid dynamics, odor capture, fine structure, biomimetic

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1 Introduction

For most animals, before odor information can be processed via the olfactory sensory nervous system, the first step is the physical contact of molecules from the surrounding medium to the sensory organ[1–4]. In many arthropods animals, olfactory neurons are located on the appendages and not within respiratory organs[5–8]. Their receptor proteins can only obtain fresh odorant molecules when the body is in motion or when fluids flow naturally and passively, for example, crustaceans actively move their antennae to promote odor capture[9–13]. Clearly, it is hard for the olfactory of arthropods to capture fresh odorant molecules. Fluid flow around the olfactory organ depends on the relative importance of inertial and viscous forces, as represented by the Reynolds number (*Re*)[12]. The fluid will pass through the object in laminar state at a low *Re*. The laminar flow is not helping for the odorant molecules staying and contacting with the olfactory sensilla[14]. For animals living in the air, the *Re* is often small due to the small velocity of the airflow[15–17]. In this situation, the structure of the olfactory organ is certainly important. Evolution has solved this problem in terrestrial arthropods, providing them with fine structured olfactory, such as antennae on many insects, antennules on terrestrial hermit crab, and pectines on scorpions[18–20]. The present study is part of a program to understand the fluid dynamics of olfactory in arthropods, an important but largely unexplored area.

The scorpion, one of the oldest living things in the land, has extraordinary ability of perception to the outside world after hundreds millions years of evolution. The pectines on the opisthosoma of the scorpion are considered one of the most important sensor organs[21]. Research evidence, formed via behavioral observations[22,23], anatomical data[19,24], and electrophysiological results[25–27], indicated to be a mechano- and olfactory function for the bilaterally paired pectines; however, predominantly olfactory appendages. Most scorpions possess a pair of pectines. The pectines have a comb-like appearance with a jointed "spine" (anterior lamella), supporting a line of movable teeth that range in number from three (genus *Euscorpius*) to more than 40 in some psammophilic buthids[28]. The ventral surface of each

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tooth contains thousands of bowl-shaped sensilla and these micro bowl-shaped sensilla are orderly arranged[19,29]. However, previous studies mainly focused on the anatomy and innervations of the pectines. Little research has been published about the fine structure of the pectines and the relationship between this fine structure and the airflow that surrounds them.

The aim of this study was to investigate the odor flow around the pecten of *Mesobuthus martensii*. We therefore presented a morphological study of the *M. martensii* scorpion, with special focus on the fine structure that aids the olfactory capturing fresh odorant molecules. Therefore, we analyzed the pecten morphology in the scorpion *M. martensii* by stereomicroscopy and scanning electron microscopy in order to shed light on possible mechanisms that may enhance odor capture. Simplified and enlarged models (contain multiple tooth model and pecten sensillum model) were established based on the key profile dates extracted from these pecten images. Odor flow around the scorpion is likely to be generated by the animal's motion relative to the surrounding air and the naturally occurring wind. The odor flow that passes the pecten can be simulated via airflow over a static model. Moving fluids over a static model has also been used to simulate flow[30–33], this is shown to be equivalent to moving the model trough static air. Furthermore, we kept the same Reynolds number and model shape to predict the flow field for different sized models and used this in numerous types of fluid mechanics calculation models[32,34]. The delicate structural features of scorpion pectines may be used for industrial development with desirable functionalities, for example, heat exchangers and porous media.

2 Material and methods

2.1 Animal samples

Sub-adult and adult females of the scorpion *Mesobuthus martensii* (Scorpiones, Buthidae) collected from wasteland in Shandong province, China, were the subjects of this study. Animals were kept in 3.8 L glass jars containing soil from the scorpions' natural habitat. Each animal was fed with one cricket every week, and lightly water twice a week. The scorpions were maintained at the Key Laboratory of Bionic Engineering, Ministry of Education, Jilin University, at constant temperature (22 ℃), relative humidity (55% – 65%), and light/dark cycle (20:00 – 07:30 hours dark, 07:30 –20:00 hours light). The anti-erosion function of the scorpion had been studied in our previous studies[35].

2.2 Odor perception experiment

For this experiment, 70 adult scorpions (5 cm to 7 cm in length from prosoma to aculeus) were selected and randomly divided into 14 groups with five scorpions per group. Six groups were designated as control groups and eight as treatment groups. The scorpions of each treatment group had their pectines covered with histological paraffin. The paraffin was melted and spread in water for cooling and better manipulability. One at a time, the scorpions were held with pincers. Before the paraffin had hardened, it was applied to the scorpions' pectines using a fine brush with just one flick per pecten[36]. The ventral surface was the main area covered with paraffin, as most pecten sensilla were located on this surface. In control groups, scorpions remained with their pectines intact; however, they were also manipulated to cause a similar level of stress (brush with water) as the treatment samples. Before the onset of the experimental tests, samples of both groups had a period of one week for adaptation.

Experiments were conducted in an equidistant diffusion apparatus as shown in Fig. 1. This apparatus had a symmetrical structure and a piece of straight glass tube connected to a glass container on each side. There was an odorant pool in the middle of the apparatus. The whole apparatus was sealed and put on a horizontal table to avoid gravitational interference. The straight glass tube was 1 m in length, and the diameter was 3 cm. The

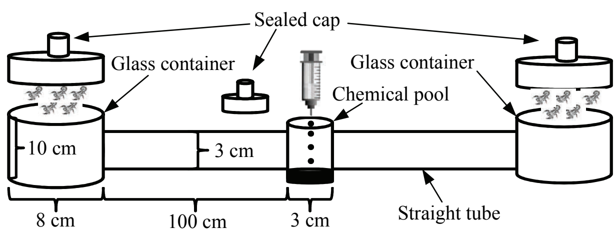

Fig. 1 Equidistant odor diffusion apparatus, consisting of a glass container, a sealed cap, a straight tube, and an odorant pool. Main dimensions are shown in the picture. Treatment group scorpions and control group scorpions were randomly placed in the left and right scorpion houses. This apparatus is completely sealed and place in a horizontal position to avoid gravitational interference and outside airflow. The odors were injected after quieting of all the scorpions. The experiment was conducted at room temperature. Odors spread freely to the glass container with identical delay. Time from injection of odors to the scorpion response of the odors was recorded.