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The adhesion of spiders to smooth surfaces

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Summary

The morphology of the adhesive setae on the legs of two spiders, *Salticus scenicus* (Clerck) and *Sericopelma rubronitens* Ausserer, was studied using scanning electron microscopy. Using live spiders, it has been shown that a secretion is not involved in their adhesion to smooth surfaces. It is concluded that the mechanism of adhesion to smooth surfaces by spiders is likely to be primarily molecular adhesion.

Introduction

Certain spiders are able to climb smooth surfaces with the aid of adhesive setae on the legs. These setae are usually aggregated in the form of a claw tuft on the tarsus. How these setae actually adhere to the substratum is still unresolved.

As part of a wider study of the morphology of the limbs of certain spiders (Roscoe, unpublished) the adhesive setae on the legs of two spiders, *Salticus scenicus* (Clerck) and a large, tropical mygalomorph spider, *Sericopelma rubronitens* Ausserer, were examined using the scanning electron microscope (SEM). Both of these spiders are able to move on a vertical glass surface without difficulty, so experiments were also carried out to determine whether any secretion is involved in their adhesion. This paper reports on the SEM findings and discusses the possible adhesion mechanism used by spiders.

Materials and methods

Live specimens of *Salticus scenicus* were collected locally and one live specimen of *Sericopelma rubronitens* was available for limited experimental work. Some specimens of *S.scenicus* were first killed in 70% ethanol and their legs prepared for scanning electron microscopy by fixing in 2.5% glutaraldehyde in phosphate buffer then dehydrating by taking through an ascending ethanol series. The legs were then either air-dried or critical-point dried from acetone. In practice the simple air-drying technique proved to be satisfactory. Finally, the specimens were coated with platinum and viewed in a Cambridge Stereoscan Mk 2a scanning electron microscope operated at 10Kv. Legs were also prepared with the claw tufts removed using a sharpened hypodermic needle. Such treatment allowed the examination of the cuticle for the presence of pores (secretory gland openings) between the setal bases. Some legs from the exuviae of *S. rubronitens* were observed in the S.E.M. while others were broken open to facilitate examination of the inner surface of the cuticle in the region of the claw tufts.

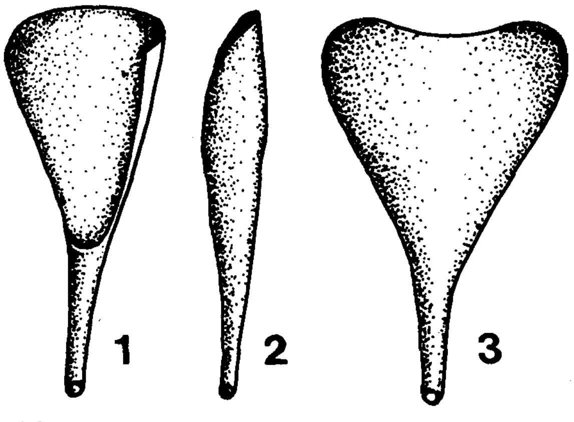
Live specimens of both species were allowed to walk across clean cover-slips which had been degreased in a 2:1 solution of chloroform and methanol. Following a walk the cover-slips were examined, using phase contrast light microscopy, to determine whether any secretion was left where a tarsus had been in contact with the glass. Observations of the movement of *S.scenicus* across a clean, dry Teflon (PTFE) sheet, held at different angles, were also made.

Results

The claw tufts of *Salticus scenicus* are positioned so as to give maximum contact with the substratum (Fig. 4). Each adhesive seta is clavate and curves towards the claws, thus maximising the available contact surface. The ventral contact surface of each seta is covered with minute setules, 3-4μm long, each with a spatulate tip (Fig. 5). Taking the shape to be triangular, the area of a tip was calculated to be *c.* 0.048μm^2. The effective contact surface of an adhesive seta has *c.* 660 setules, so the effective contact area of one seta is calculated to be 32μm^2. On average there are 40 adhesive setae per leg, giving a total number of contact points for all legs in the region of 211,000, equivalent to 10,000μm^2 contact area. The shape of the spatulate tip is difficult to visualise but after studying high power micrographs taken at different angles a profile was drawn (Figs. 1-3).

The adhesive setae of *S. rubronitens* are very long and distinctively shaped and their tips curve towards the distal end of the tarsus, forming a flat surface which makes contact with the substratum (Fig. 6). The morphology of the distal and proximal regions of the shaft of an adhesive setae is quite different. The proximal part has long, sparse setules (Fig. 6, p), while the distal region is covered by a mass of short, adhesive setules which are not specialised at their distal ends (Fig. 6, d). The adhesive setae are densely packed on both tarsus and metatarsus and are interspersed with other setae at regular intervals. Such non-adhesive setae project well beyond the adhesive setae (Fig. 7, k) and possibly have a chemosensory function.

The experiment with the living spiders revealed no



Figs. 1-3: Suggested shape of the adhesive setules of *Salticus scenicus*. **1** Dorsal view; **2** Lateral view; **3** Ventral view. The apparent heart-shape of the tip as seen in (3) is caused by the curvature of the distal edge.

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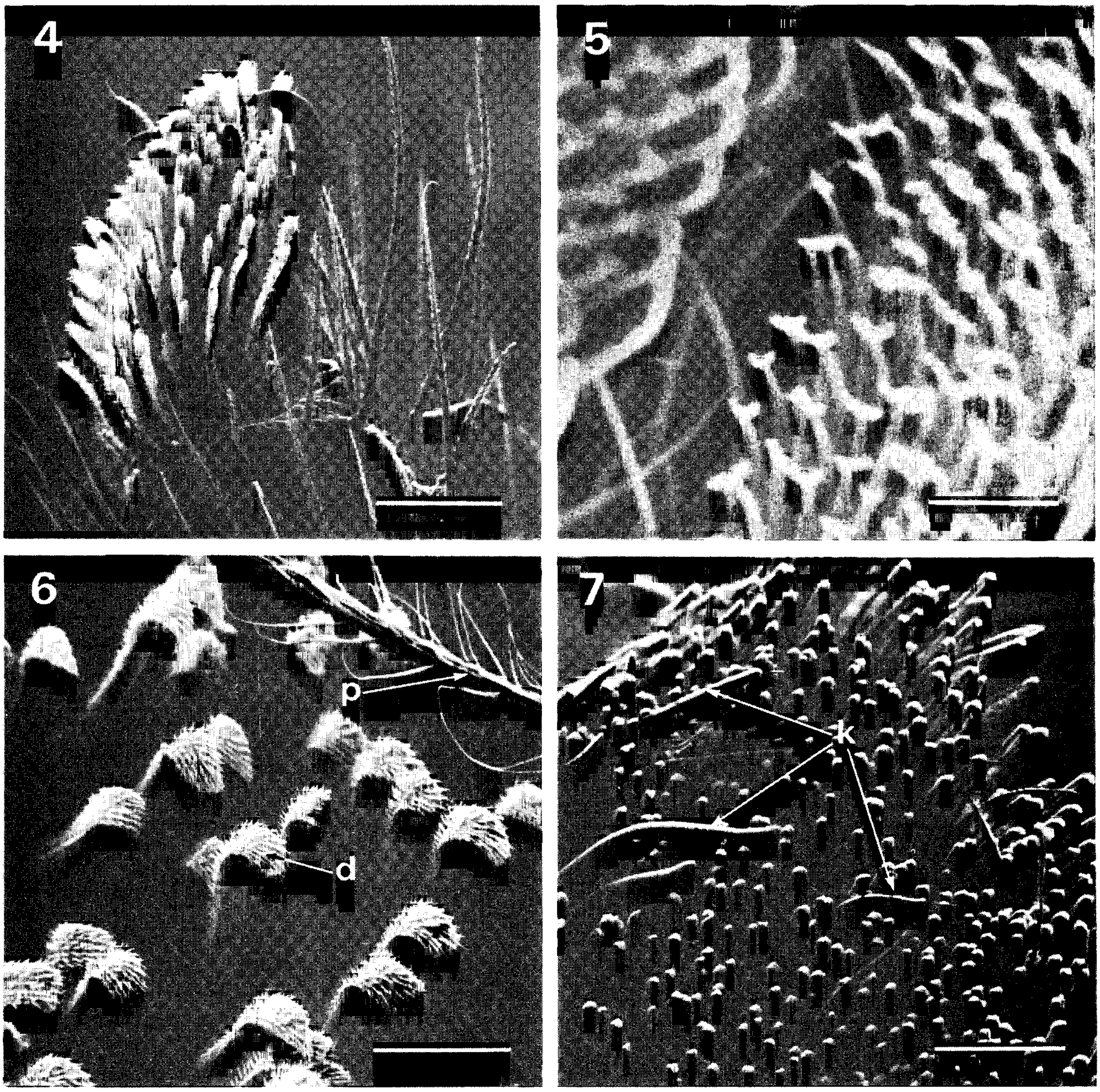
trace of secretions released from the tarsi, and SEM observations confirmed that no pores were present between the adhesive setae of either species.

A further interesting observation was made for *S. scenicus*. This spider was able to move with ease on the underside of a horizontally held Teflon sheet, and it could not be dislodged even by light tapping on the surface with a finger.

Discussion

The mechanism by which adhesion is achieved by spiders is still not fully understood. There appear to be four main possibilities: suction, mechanical adhesion to surface irregularities, adhesion due to the cohesive force of a thin fluid layer, and finally molecular adhesion. It is generally agreed that suction is the least likely of these possibilities as the shape of the tips of the adhesive setules would not allow an effective seal to be made.

Hill (1977) puts the case for mechanical adhesion. In describing the way in which adhesion occurs as a salticid spider walks up a surface he suggests that the adhesive setules catch in irregularities when the leg is moved towards the body and are released when it moves away from the body. Undoubtedly his hypothesis holds some truth for surfaces where there is a degree of roughness, but his argument fails on two counts. First, he fails to explain the way in which such spiders are able to move sideways, backwards and downwards, which they do with consummate ease, or how they are able to cling to the underside of a horizontal surface, where rugosities would be of little



Figs. 4-7: **4** *Salticus scenicus,* tarsal scopula, lateral view; **5** *S. scenicus,* adhesive setules; **6** *Sericopelma rubronitens,* adhesive setae (p = broken-off section of proximal part of shaft of a seta, d = distal end of seta); **7** *S. rubronitens,* tarsal scopula; non-adhesive setae (k) stand clear of the scopula. Scales lines = 50μm (4), 2μm (5), 25μm (6), 143μm (7).

assistance. The second point is crucial to the argument in that, even when viewed under the scanning electron microscope, glass has a surface too smooth to provide a purely mechanical purchase, yet *S. scenicus* is able to walk with ease on the underside of a horizontal piece of glass (Roscoe, unpublished). On this point alone we consider that the mechanical adhesion theory can be discounted.

Foelix (1982) supports the fluid layer theory, first propounded by Homann (1957), suggesting that the fluid layer is provided by the very thin film of water naturally present on most surfaces. It has been shown that the blowfly, *Calliphora vomitoria,* employs a lipoid secretion to form the fluid layer (Walker *et al.,* 1985), so there is the possibility that salticids and other spiders equipped with adhesive setae may similarly produce secretions. However, from the observations of the present study it is concluded that no adhesive secretion is produced by *S. scenicus* or *S. rubronitens.*

Direct molecular adhesion is possible if sufficient inter-molecular contact is made at the interface between two surfaces. Such adhesion is the result of Van der Waals forces which are exhibited between all materials (Kinloch, 1980). These forces are very weak ($0.08\text{-}42 \mathrm{KJmol}^{-1}$) and will not be effective if the two surfaces are separated by more than several Ångstroms. The strength of adhesion will depend upon the surface area and total number of contact points available for such molecular interaction.

Stork (1980) carried out a comprehensive adhesion study with a leaf beetle, *Chrysolina polita.* He concluded that the most probable mode of adhesion is direct molecular adhesion between the setae and the substratum. It is probable that the cohesive forces of a thin, fluid layer would also contribute greatly to such adhesion.

It is reasonably safe to assume that *S. scenicus,* in its normal habitat, will always encounter a fine film of water on surfaces, and therefore the mode of adhesion is likely to be a combination of direct molecular adhesion and the cohesion within this film of water. Homann (1957) has shown that a spider weighing 3 grams would have 70 ponds (pond = gram force) of capillary pressure available with all contact points established, so a water film alone could theoretically provide sufficient adhesion.

Foelix & Chu-Wang (1975) have shown that *Philodromus aureolus* (Clerck), a spider which can easily walk on the underside of a horizontal glass plate, failed to climb Teflon foil, which has a low surface energy (critical surface tension: 18.5 dynes cm^{-1}). We have shown, however, that *S. scenicus* adheres to an upturned Teflon sheet without difficulty, indicating that molecular adhesion is operating.

While recognising that further work on a variety of species needs to be done, we conclude, at this time, that the mechanism of adhesion to smooth surfaces by spiders equipped with adhesive setae is molecular adhesion, reinforced, or possibly superseded, by the cohesive force (surface tension effect) of a thin water film when present.

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