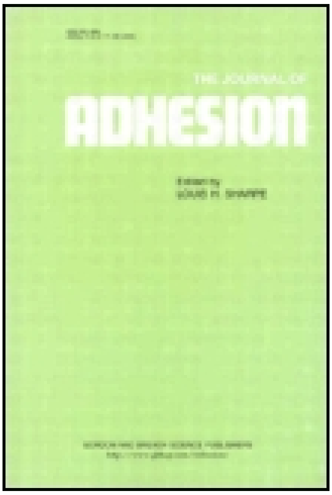

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A Study of the Adhesive Foot of the Gecko: Translation of a Publication by Franz Weitlaner

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A Study of the Adhesive Foot of the Gecko: Translation of a Publication by Franz Weitlaner

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Although it seems that gecko adhesion research is a relatively young branch of science, this recently rediscovered work presents some very old studies with quite remarkable findings. The publication of Dr. F. Weitlaner from 1902 is very impressive, as it covers many recently published topics and – even more impressively – often comes to the same conclusions and provides similar results compared with current publications. Weitlaner published his paper in German which was – at that time – very common in science. This makes it almost impossible for today's international community of bioinspired adhesion researchers to enjoy and appreciate this early gem of scientific work. Thus, we have decided to translate his paper in the hope that it finds the attention it deserves and that it inspires us to stay curious and pursue answers to the questions which have been asked for over a century.

KEYWORDS *Gecko; Adhesion; Foot; Toe;* in vivo

PREFACE

In recent years, hundreds of scientific studies have been published regarding gecko-inspired adhesives. The primary reason for this increasing interest lies in the unique properties which are combined in the adhesive system of the gecko: this natural system can quickly and repeatedly adhere to

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different surface chemistry and roughness without the use of adhesion-mediating fluids. Although these properties seem to be inconspicuous at first, there is no man-made system currently available which successfully combines all of these properties and competes with the biological adhesive system. However, there are many applications which may benefit from an artificial adhesion system inspired by geckos, ranging from climbing robots and handling systems to biomedical patches and household objects.

Although it seems that gecko adhesion research is a relatively young branch of science, this recently rediscovered work presents some very old studies with quite remarkable findings. In our opinion, the publication of Dr. F. Weitlaner from 1902 [1] is very impressive, as it covers many recently published topics and–even more impressively and despite the limited technical abilities–often comes to the same conclusions and provides similar results compared with current publications. For example, Weitlaner investigated:

- the origin of adhesive interactions (he ruled out suction as a main effect)
- the shear dependence of adhesion
- the anisotropy of adhesion
- the adhesion to different surfaces
- the maximum loading capacity

For each point in the above list, one can find very recent publications by various scientific groups all over the world, indicating that the issues tackled by Weitlaner and the problems he was confronted with more than 100 years ago are still of high interest today.

Weitlaner published his paper in German which was – at that time – very common in science. This makes it almost impossible for today's international community of bioinspired adhesion researchers to enjoy and appreciate this early gem of scientific work. Thus, we have decided to translate his paper in the hope that it finds the attention it deserves and that it inspires us to stay curious and pursue answers to the questions which have been asked for over a century.

REFERENCE

[1] Weitlaner, F., *Verh. zool. bot. Ges. Wien* **52**, 328–332 (1902).

A Study of the Adhesive Foot of the Gecko

FRANZ WEITLANER
Formerly Ship's Doctor

While staying in Singapore in the midsummer of 1901 for almost 3 weeks, I spent my evenings watching a small animal: a gecko (*Hemidactylus platyurus*). When I sat down to dine one evening on the veranda of the Hotel de la Paix, prior to the sounding of the dinner bell, my small familiar gecko appeared on the marble top of my table to snatch some of the many small mosquitoes and flying ants. As soon as it caught its prey, it rushed to the edge of the table to hide itself. After a little while, it popped around the edge again to see whether it could resume its hunt. Unfortunately for it, it had aroused my interest, and this led to its death. On my later travels, I returned to Singapore where this species is found in large numbers, and I caught some more to continue my studies. These geckos are approximately similar in size and appearance to our native [German] lizards and have an average weight of 10–30 g. The reason why I mention the weight will become apparent later. [The gecko's] ability to climb on vertical walls as well as on the ceiling is attributed to the pneumatic [suction] adhesion pads on its toes. In earlier times, it was believed that the gecko secretes a sticky substance on its toes, which, however, is unlikely since a relatively large amount of adhesive substance would be required to adhere to a fairly rough surface. The pneumatic [or suction] theory also immediately dominates [over liquid-like secretions], as it states that the gecko adheres not only with the aid of his suction cup-like adhesive toe pads in particular, but also with his complete foot, similar to our hollow hand, of course after the air is purged. My examinations about the adhesive foot of the gecko have now led me to the conclusion that the pneumatic theory by itself is not capable of explaining the phenomenon, although it may be after all an explanation which also has to be considered. While the results of these experiments are truly surprising, as confirmed by my discussions with my colleagues, the most exciting results are found when the comparison is made between living and dead animal specimens.

Experiments on dispatched [and living] animals:

1. The toes of an amputated extremity are split lengthwise down the middle (best performed with a sharpened pocket knife or scissors) and pieces of silk threads are laid into the lamellae. The two key experimental findings

Previously published in Verhandlungen der Zoologisch-Botanischen Gesellschaft in Wien, 1902 [Proceedings of the Zoological-Botanical Society in Vienna, 1902].

are [1] the dead leg adheres as well as the living, and further, [2] that it adheres also and almost as well, if the silk threads are inserted. These threads are inlaid to channel air from the side below the ridges [lamellae?] of each toe, which is itself already cut lengthwise, as well as to the *planta pedis* [sole of the foot]. The result of this experiment directly contradicts the explanations which find a main factor of adhesion to be the suction of the *planta pedis* and the lengthy cavity below the instep of each toe. Instead, the experiment proves that the adhesive scales alone provide the adhesion and additional suction of the *planta pedis* by muscle tension is present only in occasional cases on certain surfaces.

2. A further experiment with the amputated, but this time intact, gecko-extremity moreover shows that it adheres only in tension in the direction of the extremity, thus in the direction of the contracting foot muscles and the centripetal direction [of the outwardly curved] adhesive scales. However, as soon as the toe is well adhered to a surface, it then resists a comparatively high tension (for example, with tweezers) perpendicular to the surface or in the shear direction of the toes. An investigation of the quality of the surface with respect to the adhesive performance of the amputated extremity gave the following list. By far the best suited [surface for strong adhesion] is smooth, white writing paper, followed by a smooth glass plate, further, smooth metal plates, marble table, polished wood, very poorly finished brick wall (but still and particularly where geckos climb with the greatest ease!), [and] human skin. The experiments described below were performed on writing paper.
3. The third experiment I performed with an amputated extremity was the following; I tried to determine the highest possible load. Thereby I found that if the extremity, belonging to a medium-sized animal specimen of approximately 12 cm in length, adheres to a vertically suspended paper, I could load it with 80–90 g by a simple thread with an attached weight before the foot detached from the surface. If [the load is] applied [extrapolated] to all four extremities, this would be a weight of almost 400 g that the adhesive feet are capable of carrying on a vertical paper. It has to be stressed immediately that each experiment has to be performed with a fresh, unused extremity as the adhesive scales lose their [adhesive] ability rapidly for repeated experiments. [The scales] are pulled off of the toes and fall off. Meanwhile another important conclusion can be drawn from this experiment; the full adhesion phenomenon cannot be explained by air pressure since an adhesive toe has an average area of 2 mm^2. Thus the suction would have to be ideal to allow the abovementioned result of 90 g loading.
4. An experiment with living animals gives the following observation: Living animals climb extremely well on wallpapered walls and on smooth stone walls, but noticeably worse or not at all on vertical or overhanging

mirrors, thus glass walls. This would, admittedly, for the time being only prove that the small claw on the tip of each toe is of importance which should not be underestimated.

5. The [next] and most important experiment, however, is the following. If the adhesion really depends solely on the intimate conformation of the adhesive scales and the subsequent effect of the air pressure, the phenomenon must immediately cease with the application of vacuum. Unfortunately, I did not manage in the tropical cities such as Singapore, Bombay, and so on, to have an air pump at my disposal. Necessity is the mother of invention. Here I have to thank Ship Machine Operators Colognati and Hert for their kind assistance. Without their technical help it would have been impossible to perform the experiments at all. That is to say, if you descend to the ship's engine, a pipe system is typically located directly at the entrance, which can be opened with valves and is connected to an air evacuation system. Although the air evacuation is not complete, it reaches a point where the inserted baromanometer shows 60–65 cm mercury, thus approximately 6/7 of full vacuum. By using one of the valves mentioned above, I hermetically sealed a fairly large flask to this evacuation system and so I succeeded in evacuating the flask to the enormous quotient of 6/7. Of all of my experiments, I will only describe the most interesting part and omit the many preliminary tests. I took a freshly amputated gecko extremity, cut off all toes except for the middle one, clipping the claw on the tip, thus only a single toe with its adhesive scales remained on the extremity. On the site of amputation of the extremity, I then attached a weight of 10 g with a thread. Subsequently, I caused the toe to adhere to an oblong white paper strip by pulling it in shear [parallel to the plane of the paper]. As I picked up the paper strip at the end, this single adhesive toe carried the connected part of the amputated extremity as well as the attached weight with ease. (This by itself is a very interesting result and close to the limit of the possibilities of air pressure with respect to the adhesive area.) It then was a matter of placing the paper strip with the attached and load-bearing single-toed gecko extremity in a free-floating position vertically into the sealed flask. This worked out easily and the air was pumped out of the flask by the method described above until an internal pressure of 65 cm mercury was reached – and behold, the toe still adhered to the free-floating vertical paper strip and also carried the weight of the attached 10 g and the admittedly small extremity. The successful evacuation of air was confirmed by the intense, noisy inflow of air as the flask was detached from the evacuation system. Thus, if these experiments were run perfectly (and it can be repeated at any time and with better means than were at my disposal) with no counter-argument at hand, it is essential to conceptualize the adhesive mechanism of the gecko toe. If the air pressure alone is the factor controlling adhesion,

the toe should have fallen from the paper strip under its own weight as soon as the air was removed from the flask.

6. The sixth and final experiment was with a living gecko in the sealed flask, into which a paper strip was also fixed. The gecko was capable of climbing moderately well on the smooth vertical glass [of the flask] and very well on the fixed paper. The flask was then evacuated. The air was barely pumped off, after a very short time, and the gecko dropped to the bottom of the flask both from the glass as well as from the paper under spasmodic inwards contraction of its extremities, where it gradually lapsed into a state similar to death. Death would surely have occurred if I had kept the vacuum any longer. This experiment thus provides a significant contrast between a living gecko and the adhering dead extremity. The living gecko drops repeatedly from the evacuated flask despite his four extremities while the adhering dead adhesive toe stays adhered in the flask and carries the additional weight. The certainty of the evidence is based only on the dead adhesive toe performance. It is clear that the living gecko does not drop down because the air pressure does not work anymore within his adhesive system, but because he is rolling in his adhesive toes due to physical distress and pulls them off in spasmodic motions. It would be a complete mistake to draw a conclusion on the effect of air pressure based [solely] on experiments with living animals before excluding all other possibilities.

Now I rush to the overall conclusion which has arisen from my experiments: it is likely incorrect, as it was generally hypothesized until now, that air pressure alone accounts for the adherence of the gecko adhesion toe. In fact, air pressure may not even be a substantial, but only an occasional auxiliary, factor. Therefore another physical interaction has to be considered which elicits and explains the adhesion phenomena. It will be the task of further research to experimentally and microscopically state the true reason of the phenomenon. I was unfortunately unable to microscopically investigate the gecko's adhesive scales because I did not have access to a microscope, nor could I borrow one. Today one is anxious to dissect the term "adhesion" and ascribe too much importance to the air pressure phenomenon, although it will be impossible to completely discard this term. In addition to the gecko toe, which adheres at reduced pressures, there is also the example of capillarity, which can be observed on a grand scale in giant tropical trees. In their capillary vascular system, hundreds of kilograms of water are lifted out of the ground to the high twigs and leafs, thus attaining the power equivalent to many horsepower.

The gecko overall is a very interesting animal, and how creepy it is for the person who is in the tropics for the first time, when it is very close at night, for example, near the bed, and suddenly lets out its loud call. Upon further observation, one is delighted to observe the fairly high intelligence of the animal. Apart from the slight translucence of his body, the lateral skin fold, the darting sticky tongue, the satin-like adhesion apparatus on the toes, the peculiar manner of running on the ground and along the walls, it is also very interesting to see its pupil, which runs vertically along the whole cornea, while the spiked edges of the iris grip into each other like gearwheels during closure. The pupil closes and opens thus like a theater curtain and not concentric like, for example, the human pupil. In short, the gecko shows in all of his body parts an admirable adaption to his profession, which consists of catching mosquitoes at night and keeping our rendezvous.