Abstracts for SEB Gothenburg 2017 - Biological adhesives: from biology to biomimetics

Enzymes involved in bioadhesives production in invertebrates (mussels and oysters) and macroalgae

Claire Hellio (Université de Brest, France)

The growing demand to develop a novel, environmentally friendly antifouling or bioadhesive material is ever increasing. Bioinspiration is an attractive alternative in developing such a material, learning from nature?s own designs and solutions and transferring them to solve particular problems. In order to achieve this goal, the actual mechanisms and strategies that evolution has produced needs to be elucidated from the subject species. The work presented in this talk will focus on bioadhesion strategies used by marine organisms and how from fundamental studies, 1) we have develop a new bioassay for testing the activity of compounds for inhibition or promotion of adhesion of various marine organisms by studing oxidising mechanisms and key enzymatic pathways ; 2) we have made major advances in the caracterization of the process leading to adhesion of oysters and the adhesive composition analysis at various life stage.

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Investigating the relative roles of adduction and adhesion in tree frog climbing

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The adhesive mechanisms of climbing animals have become an important research topic in recent years because of their biomimetic implications. Here, we investigate the climbing abilities of hylid tree frogs on vertical cylinders of differing diameter and surface roughness in order to investigate the relative roles of adduction and adhesion in climbing. Tree frogs adhere using their toe pads and subarticular tubercles, mainly by wet adhesion. Our hypothesis was that, on an effectively flat surface (the largest 120 mm diameter cylinder), adhesion would be the only means by which tree frogs could avoid falling, but on the two smaller diameter cylinders (44 mm and 13 mm), frogs could additionally utilise adduction forces by gripping the cylinder either with their limbs outstretched or by grasping around the cylinder with their digits, respectively. The frogs? performance would also depend on whether the surfaces were smooth (easy for the frogs to adhere to) or rough (non-adhesive). Our findings confirmed our expectations in that frogs climbed fastest on the narrowest smooth cylinder where adduction and adhesive forces could combine, but were unable to climb the largest diameter rough cylinder Using an optical technique to visualize substrate contact during climbing on smooth surfaces, we also observed an increasing engagement of the subarticular tubercles on the narrower cylinders. Additionally, on a multiple force plate climbing apparatus, compressive forces were recorded, particularly when climbing rough surfaces, indicating the use of a clamping grip. These results support our hypotheses and have relevance for the design of climbing robots.

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Abstracts for SEB Gothenburg 2017 - Biological adhesives: from biology to biomimetics

Adhesion with applications to biological systems

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How can a lizard adhere and move on a stone wall, or a fly on a glass window,or a tree frog on a plant leaf? In this presentation I will talk on some fundamentalsof adhesion with applications to bioadhesion. I will discuss how surface roughness,viscoelasticity and capillary bridges influence adhesion and adhesion hysteresis. Iwill present the experimental results for the adhesion between silicone elastomerand smooth and rough glass surfaces in dry and wet conditions. I will also remarkon the relation between adhesion and friction.

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Bioadhesion of mucilaginous seeds

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Seeds and fruits of many plants are able to produce a sticky, gel-like capsule, i.e. mucilage envelope, after hydration. It represents a modified cell wall and is composed of polysaccharides: pectins, hemicelluloses and cellulose. The mucilage adhesion is of importance for the seeds and fruits dispersal by the animals (egzozoochory). The main mass of the mucilage envelope constitute pectins, which have a great ability to water binding. Cellulose forms characteristic ?skeleton? made of long, unbranched fibrils and prevents the mucilage release from the seed surface. The chemical composition allows distinguishing two types of mucilage in different plants. Pectic mucilage is characteristic for e.g.*Linum usitatissimum*, whereas cellulose mucilage for e.g.*Plantago lanceolata*. In our mechanical tests, both mucilage types demonstrated different adhesive properties depending on the water amount. Immediately after mucilage formation the adhesion of mucilage envelope was very low. Then it was increasing gradually with the loss of water. Maximal values of the adhesion varied between 33 N for the cellulose mucilage and 91 N for the pectic one. During further mucilage desiccation, the adhesion force was decreasing very rapidly after reaching its maximum in the case of cellulose mucilage, or decreasing gradually in the case of the pectic mucilage. Our experimental data show that different chemical composition of the mucilage influences its adhesion properties.

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Bioadhesive PEG-Chitosan Nanoparticles as Gene Delivery Vehicle

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Our goal here is to synthesize PEGylated adhesive chitosan nanoparticles with tumor homing peptide and use these nanoparticles as a gene delivery vehicle for glioblastoma multiforme (GBM). PEG-conjugated chitosan is essential to improve colloidal stability and water solubility of chitosan at physiological pH. Here, we selectively target amino groups of chitosan and used PEG-SVA for this conjugation reaction. We characterized reaction steps through TNBS and Ellman?s assay and obtained chitosan nanoparticle diameters that ranged between 70-120 nm. These particles have the capability to pass through the tight-junctions between epithelial cells, and our future studies will focus on the gene delivery potential of these nanoparticles via nasal route. This proposed system will have a potential to promote apoptosis and decrease viability of GBM cells. The therapeutic approach used in this project may be useful to eliminate the difficult surgical operation and heavy chemotherapies in cancer patients which negatively affect whole body and result in inefficient delivery of the drug due to the presence of blood-brain-barrier.

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Biological Adhesion of Flatworms

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Man-made adhesives contain hazardous components which are toxic and cause skin irritations, respiratory problems or they are suspected carcinogens. Furthermore, these adhesives perform poorly in wet environments. In contrast, biological adhesives produced by animals can be considered as non-toxic, tissue compatible, and they are able to function under wet conditions. However, little is known about the mechanisms underlying biological adhesives. The free-living flatworm *Macrostomum lignano* can attach and release several times within a second on any substrate in seawater. We have identified adhesive proteins using transcriptomics, differential gene expression, Mass Spectrometry, In situ Hybridization screening, Lectin staining and pull-down, specific antibodies, and light- and electron microscopy. The flatworm duo-gland system consists of an adhesive-, and a releasing gland cell, and a modified epidermal cell, the anchor cell. We now have identified two key adhesive proteins which result in a non-adhesive phenotype upon RNAi knock-down. Flatworms comprise a diverse phylum including marine and freshwater species as well as parasitic representatives. Preliminary data suggest that adhesive proteins are not conserved between different flatworm taxa. We aim for understanding the fundamental mechanisms that mediate adhesion and release in flatworms with the goal to generate a flatworm-derived biomimetic glue that can be applied in biomedicine and industry.
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Biomimetic adhesive proteins inspired on sea urchin adhesives

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In nature, marine adhesive proteins show remarkable adhesive properties, biocompatibility, and biodegradability, being considered promising candidates for the development of new environmentally friendly adhesives for biomedical and industrial applications, especially in aqueous conditions.
Chemical attachment is the main adhesive strategy of sea urchins that rely on specialized adhesive organs - tube feet. The later enclose a duo-gland adhesive system, capable of producing separately adhesive and de-adhesive secretions.
Recently, the differential proteome analysis of *Paracentrotus lividus* tube feet and of its secreted adhesive, provided an unprecedented insight into the key proteins involved in sea urchin reversible adhesion and highlighted *Nectin* as the first known sea urchin tube foot adhesive protein. This protein is highly over-expressed in the adhesive disc relatively to the motile stem, being an actual component of the secreted adhesive.
Sea urchin Nectin contains 6 F5/8 type C-domains, also found in sea star footprint protein Sfp-1, providing it with the ability to bind carbohydrates, also present in reversible adhesives, thus indicating a cohesive role. Nectin has also been shown to have an adhesive role in sea urchin embryos, being involved in substrate adhesion of embryonic cells.
Employing a biomimetic strategy seeking to identify and replicate adaptive biological attributes with potential technological applications, *Nectin* recombinant expression is in progress for the full-protein sequence, but also for some protein-fragments containing only few domains. The adhesive properties of the obtained purified recombinant proteins are being investigated using atomic force microscopy, ellipsometry and surface plasmon resonance.

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Characterising and quantifying the adhesion-related behaviours of barnacle larvae

Nick Aldred (Newcastle University, United Kingdom)

I will begin this talk by presenting the main objectives of Working Group 1 of the new, bioadhesion-focussed, COST Action 15216; briefly outlining some shared challenges that we aim to address in the coming years. These include topics as diverse as characterisation of non-protein constituents of adhesives, heterologous production in host-vector systems and reconciling sequence similarity with structural and functional similarity in adhesive biomolecules. One such consideration when discussing the adhesion of higher organisms particularly, but all biological systems to some extent, is the role of behaviour during attachment. It is tempting to reduce the study of biological adhesion to an exercise in molecular biology/chemistry, however neglecting the importance of adhesion behaviour is risky. Body movements can be crucial in the effective formation and release of an adhesive bond and selection of surfaces for attachment is central to applied adhesion problems like biofouling. Barnacle larvae have a supremely adapted and highly complex suite of adhesion behaviours that remain poorly understood, from macro-scale surface exploration that occurs prior to settlement, down to the micro-scale movements associated with temporary adhesion. Marine biofouling is a commercially and environmentally important application for bioadhesion research, and well represented in this COST Action. Among the many biofouling organisms, barnacles are considered to be of particular commercial significance and their larval settlement is the logical point of intervention.

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Competing with barnacle cement: Microstructures that reduce permanent underwater adhesion of barnacles

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Sessile marine organisms such as barnacles, mussels, and tubeworms use solidifying glues for their fixation to substrates of any kind, seemingly irrespective of their surface chemistry and topography. This implies, these glues fulfill a fundamental prerequisite for a strong and reliable adhesive joint: they readily wet all substrate materials before solidification. Therefore, to prohibit permanent adhesion of marine organisms, a surface has to prevent wetting of such glues. New developments in super-repellent surfaces have shown that so called re-entrant surface microstructures repel liquids even of extremely low surface tension independently of their inherent material?s wettability. To test whether such re-entrant microstructures also reduce permanent adhesion of marine hard foulers, the amount of biofouling, especially *Balanus improvisus*, on different silicone substrates was evaluated in a static field trial in the Baltic Sea. Silicone substrates covered with mushroom-shaped micropillars (MSMs, as re-entrant structure), i.e. micropillars with broadened terminal tips, and silicone substrates covered with simple micropillars (MPs) of the same dimension, initially accumulated similar numbers of attached barnacles. However, after 13 weeks all barnacles were detached from surfaces covered with MSMs. Instead, after 17 weeks still 42% of initially attached barnacles remained attached on the surfaces covered with MPs. Visualizations of the contact interface between surface microstructures and barnacles revealed that their cement only wet the terminal contact elements of MSMs, but completely surrounded MPs. Therefore, barnacle cement generated a much higher contact area and interlocking with MPs compared to MSMs. These findings may be of importance for future non-toxic antifouling strategies.

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Double networks and slug glue: Integrating mechanics and sequence data to characterize an unusually tough hydrogel adhesive

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When threatened, the terrestrial slug *Arion subfuscus* secretes a viscous material from its dorsal surface, which rapidly sets into a tough, adhesive double network hydrogel. High throughput sequencing (RNA-seq) was used to determine the primary structure of all the common proteins in the glue. All but one of the proteins are novel, but they have conserved domains with cross-linking functions. The proteins fit into two main categories. The first consists of five proteins with multiple vWFa and EGF domains. These domains are typically involved in calcium-dependent intermolecular cross-linking. The second category consists of a highly abundant and relatively diverse group of at least eleven proteins that are all relatively small (10-15 kDa), and all contain one of three known ligand-binding domains (C-lectin, C1q, H-lectin). In addition, the enzyme catalase is abundant in the glue, as is a novel protein with no known homology. These results suggest a model where calcium forms sacrificial cross-links between vWFa/EGF-rich proteins. Such cross-links would toughen the gel by stiffening it, while allowing high extensibility. The lectin-domain containing proteins are hypothesized to oligomerize to present multiple different binding sites to bring different components of the glue together. Catalase may be involved in oxidative cross-linking. Further work is needed to determine how the structure of the novel protein relates to its function; it appears to be oxidatively linked into large multimers. This work demonstrates the value of whole transcriptome sequencing in biological adhesives, which often have novel proteins.

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Enzymes involved in bioadhesives production in invertebrates (mussels and oysters) and macroalgae

Claire Hellio (Institut Universitaire Européen de la Mer (IUEM), France)

The growing demand to develop a novel, environmentally friendly antifouling or bioadhesive material is ever increasing. Bioinspiration is an attractive alternative in developing such a material, learning from nature?s own designs and solutions and transferring them to solve particular problems. In order to achieve this goal, the actual mechanisms and strategies that evolution has produced needs to be elucidated from the subject species. The work presented in this talk will focus on bioadhesion strategies used by marine organisms and how from fundamental studies, 1) we have develop a new bioassay for testing the activity of compounds for inhibition or promotion of adhesion of various marine organisms by studing oxidising mechanisms and key enzymatic pathways ; 2) we have made major advances in the caracterization of the process leading to adhesion of oysters and the adhesive composition analysis at various life stage.

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Exploring the role of mechanical interlocking and hydrodynamic friction in tree frog attachment

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Tree frogs can attach to smooth and rough surfaces using their versatile toe pads. Despite considerable progress in the understanding of the mechanisms of tree frog attachment (e.g. ?wet adhesion?), it is still not fully understood how these animals manage to attach to a wide range of natural substrates.
We present the results of an experimental investigation of the role of mechanical interlocking between superficial toe pad structures and substrate asperities in the tree frog species *Litoria caerulea* and *Hyla cinerea*. Using a rotation table setup, we quantified the adhesive and frictional contact forces and stresses of frogs clinging to smooth, nano- and microrough substrates. The transparent test-substrates enabled quantification of the contact area by frustrated total internal reflection. The maximum contact forces were not significantly different for roughnesses between 0.1 nm and 15 ?m in both species. This indicates that mechanical interlocking does not contribute to attachment, assuming that a change in roughness does not adversely affect mechanical interlocking and other possibly involved mechanisms of force generation.
Further, we studied the origin of friction in whole animal attachment. The friction coefficient scales with normal load with scaling exponents of -0.81 (*L. caerulea*) and -0.86 (*H. cinerea*) indicating a strong contribution of hydrodynamic lubrication to whole animal friction independent of substrate roughness. Importantly, in friction measurements the contact area was largely formed by belly?substrate contact.
Overall, our experimental findings contribute to a better understanding of the complex interplay of attachment mechanisms in tree frogs? toe pads.

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From bivalve cement to biomimetic mineral adhesive

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Attachment of bivalves to a natural substrate in water is one of their physiological functions. Many types of adhesives have been inspired and developed from molecular design of these biomaterials (for instance mussel byssus). The oysters and other bivalves produce a mineral adhesive for attaching to hard surface. This adhesion is achieved by a biologically induced extraperiostracal calcification, called bivalve cement, it is very different to traditional polymer adhesive. A better understanding mechanism of the bivalve cement formation will be helpful for oyster reef building which has been considered as solution for coastal erosion, it will also lead to a medical adhesive for bone fracture healing application.

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Identification and localization of various tyrosinase isoforms in the foot of the blue mussel Mytilus edulis

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The byssus is a proteinaceous holdfast allowing marine mussels to secure themselves on rocks in the wave-swept intertidal zone. It consists of a bunch of load-bearing threads each terminating in a flattened plaque that mediates adhesion to the substratum. Byssal threads and plaques are formed by the auto-assembly of a dozen of proteins originating from three distinct glands enclosed in the mussel foot. All these proteins differ in size, amino acid composition and sequence but they share a common distinctive feature: the presence of 3,4-dihydroxyphenylalanine (DOPA), a residue formed by the post-translational hydroxylation of tyrosine. This modified amino acid fulfils two important roles in the byssus: it mediates physicochemical interactions with the surface (adhesion) and it is involved in the formation of cross-links between the different proteins (cohesion). It is generally accepted that the latter is related to the oxidation of DOPA to DOPA-quinone. Tyrosinase, a specific enzyme co-secreted with byssal proteins, can catalyse both the o-hydroxylation of tyrosine to DOPA and the further oxidation of DOPA to o-quinone. In the present study, five tyrosinase isoforms were retrieved from a foot transcriptome of the mussel *Mytilus edulis*. They showed high similarity with tyrosinases from other mussel species and all the sequences were included in a phylogenetic analysis. The specific expression of the transcripts in the foot was experimentally confirmed by RT-PCR. Finally, *in situ* hybridization experiments demonstrated that the different isoforms are gland-specific, suggesting they might be adapted for the modification of specific proteins within the byssus.

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Innate ?printing? of glue affects robustness of spider silk thread anchorages and helps to explain the evolution of aerial webs

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Building behaviour in animals extends biological functions beyond bodies. In spiders, the evolution of economic web shapes as a key for ecological success has been related to the emergence of high performance silks and thread coating glues. However, the role of thread anchorages has been widely neglected. Here we show that orb-web (Araneidae) and hunting spiders (Sparassidae) use different silk application patterns that determine the structure and robustness of the joint in silk thread anchorages. Silk anchorages of orb-web spiders show a greater robustness against different loading situations, whereas the silk anchorages of hunting spiders have their highest pull-off resistance when loaded parallel to the substrate along the direction of dragline spinning. By using morphometric and model approaches, we show how the placement of the structural thread within the instantly produced glue patch affects pull-off forces in orthogonal loading situations. These results show that the way how glue is applied, crucially enhances the toughness of the anchorage without the need of additional material intake. Preliminary results of a broad comparative analysis of spinning patterns and structural parameters of the anchorages across the spider tree of life indicate their effective refinements throughout evolution. Our results suggest that the behavioural ?printing? of glue and silk into thread anchorages was a prerequisite for the evolution of extended silk use in a 3D-space and the emergence of superior fibres. This highlights the role of attachments in the evolution of animal architectures, and suggests a high potential of such studies to inspire novel adhesive applications.

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Investigations of Adhesion in Bio-replicated Microstructure Surfaces: Effects of Shape, Size, and Complexity of Patterns

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Adhesion and frictional surface phenomena are widespread in biological systems as well as in most technical systems. Indeed, they are influential factors for controlling the performance and durability of many physical systems. Beside the surface chemistry, the real contact area is an important parameter to modulate adhesion and friction forces acting between soft surfaces, which decidedly depends on surface micro-structuring. Adhesion and friction also play a significant role in the interaction of biological systems. In nature, almost all the biological surfaces are organised over a diverse range of surface structuring which allows for an evolutionary optimisation of their surface functionalities which proved to be inspiring for technical products like the anti-adhesive behaviour of the leaves of the rubber tree, the self-cleaning properties of the lotus leaves, or insects trapping in carnivorous plants (slippery surfaces). Three different plant leaves were selected as biological model surfaces, according to the different size range (0.5-100µm), distinct shape, and complexity of their surface microstructures. A two-step micro-replication technique was used to fabricate polymeric replicas directly from original plant leaves. Adhesion force measurements were performed by using a dynamic pull-off tester coupled with real-time contact recording. Adhesion force characteristics were consistently measured for each polymeric replica and for a smooth polymer surface, by detaching the contact with a model adhesive system. Results reveal that the surface micro-structuring has a significant influence on adhesion force characteristics of tested polymeric surfaces. Variations in adhesion force were observed when changing the normal applied load, and altering total contact time.

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Learning from Northern clingfish: New bio-inspired suction cups attach to rough surfaces

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Normally artificial suction cups only attach to smooth surfaces. A little fish, which is suspiciously named Northern clingfish (Gobiesox maeandricus), can attach to a huge variety of surfaces ranging from totally smooth up to as rough as sandstone. Moreover, this little fish of the marine intertidal can even hold onto slimy biofilm covered surfaces. These abilities are highly desirable for technical applications. Previously, we showed that the suction cup?s elasticity in combination with its hierarchical structures are key features enabling the fish to attach to challenging surfaces. The hierarchical structures on the disc margin consist of papillae (~150µm) covered with rods (~5µm), which are divided into tiny filaments at their tips (~0.2µm). These specialized structures enable not only a perfect adaptation to the surface irregularities of a substrate, but also increase the friction properties of the disc margin. The increased friction forces act against the forces pulling the disc margin in central direction during detachment. Therefore, the increased friction properties of the disc margin delay failure of the suction cup and result in increased attachment forces. Transferring these principles, we recently developed a bio inspired suction cup. Our bioinspired suction cups gains tenacities up to 70KPa on surfaces as rough as 0.27 mm grain size (roughest surface in the experiment). On substrates of the same roughness the bio inspired suction cups attached several weeks under water in an experimental setting. Our suction cups could be technically applied in fields such as surgery or whale tagging.

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Lotus and pitcher plant:Role models for slippery surfaces in air and under water

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Slippery surfaces can be found directly in nature but also when the principle of a natural surface is extended. The former can be observed in the carnivorous pitcher plants *Nepenthes* spp. These make use of hydrophilicity on their rim. The local surface holds a fluid film, on which insects cannot adhere and slip into the pitcher. An artificial transfer is the so-called SLIPS-approach (slippery liquid-infused porous surface), in which it is possible to create an omniphobic surface, depending on the chosen lubricant. One example of the latter is the lotus plant *Nelumbo nucifera*. The purpose of its superhydrophobicity is self-cleaning but when submerged, those surfaces hold an air layer. In a technical implementation the contained air is able to reduce the wall shear stress in flow fields. Since the water is no longer in contact with a solid anymore but next to a medium of lower viscosity, it can slip off and is less decelerated. A boehmite structure, which grows on aluminum, was used as a porous surface for both the superhydrophobic and the omniphobic surfaces. To make the boehmite structure superhydrophobic, it was silanized. The reduction of wall shear stress of the air layer could be shown in water tunnel experiments with particle image velocimetry (PIV). Following the SLIPS approach the boehmite structure was infused with different lubricants. The omniphobic performance was tested by contact angle measurements, the slip-off behavior of different liquids, calculation of the surface energy, freezing rain trials, and measurement of the adhering force of hemolymph.

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Modular resilin fusion proteins ? from molecules to materials

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We have studied the behavior of adhesive and elastic fusion proteins. The protein design included a resilin-like peptide (RLP) coupled with adhesive domains. The study presents different aspects of the proteins and materials derived from the molecular to macroscopic scale. We employed for instance single molecule force spectroscopy, cryo-TEM tomography and quartz crystal microbalance together with spectroscopic methods to understand the assembly and behavior of the molecules and materials. The resilin behavior is much regulated by the controlled conformational changes induced by change of the pH, which are in key role in formation of adhesive materials.

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Scaling Principles for Understanding and Exploiting Bio-Inspired Adhesion

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A grand challenge in the science of adhesion is the development of a general design paradigm for adhesive materials that can sustain large forces across an interface yet be detached with minimal force upon command. Essential to this challenge is the generality of achieving this performance under a wide set of external conditions and across an extensive range of forces. Nature has provided some guidance through various examples, e.g. geckos, for how to meet this challenge; however, a single solution is not evident upon initial investigation. To help provide insight into nature?s ability to scale reversible adhesion and adapt to different external constraints, we have developed a general scaling theory that describes the force capacity of an adhesive interface in the context of biological locomotion. We have demonstrated that this scaling theory can be used to understand the relative performance of a wide range of organisms, including numerous gecko species and insects, as well as an extensive library of synthetic adhesive materials. We will present the development and testing of this scaling theory, and how this understanding has helped guide the development of new composite materials for high capacity adhesives. We will also demonstrate how this scaling theory has led to the development of new strategies for transfer printing and adhesive applications in manufacturing processes. Overall, the developed scaling principles provide a framework for guiding the design of bio-inspired adhesives.

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Sticking To The Dirtiest Surfaces: The Moth-Specialist Spider Cyrtarachne akirai Uses Prey Scales to Increase Adhesion Of Aggregate Silk Glue

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Contaminants decrease adhesive strength by interfering with substrate contact. Moths adhering to spider webs present an ideal model to investigate how natural adhesives overcome contamination because moth's sacrificial layer of scales rub off on sticky silk, allowing them to escape. The Cyrtarachninae spiders evolved webs that overcome this and specialize on hunting moths. We compare the adhesive performance of Cyrtarachne glue to more typical spider glues to understand how Cyrtarachne glue overcomes dirty surfaces. We compare the spreading and adhesion of spider glues on pristine moth-wings to wings denuded of scales and smooth glass. We manipulated the hydrophobicity of these surfaces to tease apart the influence of surface chemistry vs microstructure for adhesion. High-speed videos show that upon contact with moth-wings the unusually low viscosity of Cyrtarachne aggregate glue allows it to seep beneath the protective scales and then to accelerate spreading along the cuticle. Other spiders? glue droplets were unable to penetrate the scales, minimizing adhesion. Cyrtarachne adhesion on nude moth-wings was similar to glass showing that differences in topography, not chemistry, were responsible for the increased adhesion. Making moth-wings hydrophilic increased adhesion and spreading in other species, allowing their glue to spread beneath the scales similarly to Cyrtarachne. Hydrophilic tests however, showed increases in bulk failure for Cyrtarachne leading to decreases in adhesion strength from overspreading. Cyrtarachne uses the extremely low viscosity of its glue to take advantage of the low surface energy and topography of moth-wings, spreading rapidly across the cuticle without sacrificing cohesive strength.

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Technical patterning inspired from nature induces scale invariant behaviours in wetting and adhesion

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Nature offers many examples of how a topographic surface pattern may control wetting or adhesion phenomena: the most popular examples are probably on one hand water-repellent properties of the lotus leaf and on the other hand the sticking capabilities of gecko. Modern techniques of texturation make possible to mimic natural surfaces in order to investigate the resulting functionality with controled and tunable topography.
In this work, we first discuss the conditions for contact formation between soft elastic hemispheres and soft elastic substrates micropatterned with hexagonal pillars using a home-made Johnson-Kendall-Roberts (JKR) apparatus. Both deformable solids are made of cross-linked commercial polydimethylsiloxane (PDMS). Then, we describe the structural role of the pillars (aspect ratio) in the contact hysteresis during loading and unloading. Contacts may be of various types depending on the surface micro-topography, leading to very different macroscopic behaviours. We show that the affine variation of the surface pattern aspect ratio lead to a scale invariant behaviour of the contact formation.
Secondly, we discuss the wetting behaviour of these micro-topographically patterned substrates. It is shown that similar wetting situations are achieved when varying simultaneously and homothetically the topographical parameters (width of the pillars and inter-pillar distance). This corresponds to the scale invariance which was previously pointed out in the adhesion experiments and this law is demonstrated for a wide range of pattern dimensions. Our results show that either of those two phenomena (adhesion and wetting) can be simply controlled by the proper choice of a dimensionless ratio of topographical length scales.

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Abstracts for SEB Gothenburg 2017 - Biological adhesives: from biology to biomimetics

The Arachnocampa fishing lines

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Insects use adhesives in highly diverse ways, either for attachment, egg anchorage, mating or as active resp. passive defence. The most interesting function, however, is the use of bioadhesives to capture prey, as the bonding has to be performed within milliseconds and under unsuitable conditions (i.e. movement of prey, variable environmental conditions, unfavourable attack angle, kinetic energy of flying insects) to be nevertheless successful. While much is known about the adhesive and mechanical properties of the best example, the spiders web and its different threads, less is given for other hunters as the world-renowned glowwormArachnocampa luminosa.In the following study a detailed characterization of its prey capture system from the macroscopic to the ultrastructural level is performed and its tensile and strain properties of the fishing lines measured. The results provide unique insights into the glue composition, formation and its properties, adapted to the cave habitat and prey the animals catch with their sticky fishing lines.

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Abstracts for SEB Gothenburg 2017 - Biological adhesives: from biology to biomimetics

The impact of naupliar feeding levels on cyprid adhesive production in the barnacle Balanus amphitrite

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B. amphitrite is a cosmopolitan barnacle that biofouls manmade structures causing large-scale costs to the maritime industry. Adult barnacles release newly hatched nauplii into the plankton to feed on phytoplankton. Nauplii moult through several stages until moulting into the specialised settlement stage, the cyprid. Settlement and adhesion of the cyprid is arguably the barnacles most important life stage as failure results in mortality. While impacts of naupliar food quality and quantity have been examined in terms of cyprid settlement little has been undertaken to examine the impact on their adhesive production. Seven different feeding regimes were used to grow newly released nauplii to cyprid stage. After storage at 6 °C for 3 days 20 cyprids from each feeding regime were imaged to gain an estimate of lipid quantity. The remaining cyprids from each regime (approx. 80) were allowed to settle over 24h on acid washed glass before staining with congo red to image the cyprid adhesive. Stained adhesive plaques were photographed and the average area determined for each feeding regime. Feeding regime changes resulted in significant differences in the area of cyprid adhesive plaques. At high levels of availability, the algal species had an impact with the diatom *Skeletonema costatum* resulting in significantly smaller plaques than a mixed diet or *Tetraselmis suecica*. When fed at low levels single species diets resulted in significantly reduced sized plaques compared to mixed diets.

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