Entomology: a multitude of cross-disciplinary opportunities

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Abstract. A noteworthy feature of entomology is the opportunity for it to be practically integrated into our lives. It stretches out over a wide spectrum of useful applications across many scientific fields. Several challenges to fully understanding the complexity of entomology are presented, such as considering its vast research paradigm and raising awareness as to the importance of insects on a global scale. The current study offers an interdisciplinary outlook on insects regarding their potential role in human surgical interventions. This is achieved through the description of anatomical features and their biomechanical manifestations, observed in rare neuropteran and dipteran insect species from the European fauna, documented by the author. Empirically justified parallels between insect anatomy and advancement in surgery are exemplified through analysis of evident mechanical properties of legs in *Mantispa aphavexelte* (U. Aspöck & H. Aspöck, 1994) and *Rainieria calceata* (Fallén, 1820). In addition, suggestions on implementing specific examples of insect biomechanical design in robot-assisted surgery setups are made.

Samenvatting. Een opmerkelijk kenmerk van entomologie is de mogelijkheid om het praktisch te integreren in ons leven. Het strekt zich uit over een breed spectrum van nuttige toepassingen in vele wetenschappelijke gebieden. Er zijn verschillende uitdagingen om de complexiteit van entomologie volledig te begrijpen, zoals het in ogenschouw nemen van het enorme onderzoeksparadigma en de bewustwording van het belang van insecten op wereldschaal. De huidige studie biedt een interdisciplinaire kijk op insecten met betrekking tot hun mogelijke rol in chirurgische ingrepen bij mensen. Dit wordt bereikt door de beschrijving van anatomische kenmerken en hun biomechanische manifestaties, waargenomen bij zeldzame Neuroptera en Diptera insectensoorten uit de Europese fauna, gedocumenteerd door de auteur. Empirisch onderbouwde parallellen tussen insectenanatomie en vooruitgang in de chirurgie worden geïllustreerd door analyse van duidelijke mechanische eigenschappen van poten bij *Mantispa aphavexelte* (U. Aspöck & H. Aspöck, 1994) en *Rainieria calceata* (Fallén, 1820). Daarnaast worden suggesties gedaan voor het implementeren van specifieke voorbeelden van biomechanisch ontwerp van insecten in robot-geassisteerde chirurgieopstellingen.

Résumé. L'une des caractéristiques remarquables de l'entomologie est la possibilité de l'intégrer concrètement dans notre vie. Elle s'étend à un large spectre d'applications utiles dans de nombreux domaines scientifiques. Plusieurs défis sont à relever pour comprendre pleinement la complexité de l'entomologie, comme la prise en compte de son vaste paradigme de recherche et la sensibilisation à l'importance des insectes à l'échelle mondiale. L'étude présentée ici offre une perspective interdisciplinaire sur les insectes en ce qui concerne leur rôle potentiel dans les interventions chirurgicales humaines. Pour ce faire, elle décrit les caractéristiques anatomiques et leurs manifestations biomécaniques, observées chez de rares espèces d'insectes neuroptères et diptères de la faune européenne, documentées par l'auteur. Des parallèles empiriquement justifiés entre l'anatomie des insectes et les progrès de la chirurgie sont illustrés par l'analyse des propriétés mécaniques évidentes des pattes chez *Mantispa aphavexelte* (U. Aspöck & H. Aspöck, 1994) et *Rainieria calceata* (Fallén, 1820). En outre, sont formulées ici des suggestions sur la mise en œuvre d'exemples spécifiques de conception biomécanique d'insectes dans des installations de chirurgie assistée par robot.

Key words: Neuroptera — Robot-assisted surgery — Insect functional morphology — Interdisciplinary relationships — Biomechanics — *Mantispa* — *Rainieria*.

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A brief note on observation seen as a major methodological advantage

Observation is essential, even for the most demanding scientific task. It has two aspects that qualitatively affect the inferences from a given study, namely *depth* and *appropriacy* of the initial observation. *Interpretative ingenuity* and aptly defined *span of sought research complexity* underpin advancement. Reliance on verified circumstances and smart extraction of data from a specified observation naturally predispose to reaching the desired scientific goal. The resourceful perspective to adopt an imitative approach to technological progress through "copying" designs seen in nature has been already acknowledged – such an approach fosters sensibility to make rational and innovative suggestions. This is why the current paper leans towards a forward-looking viewpoint to discern practicably relevant cross-disciplinary links between entomology and other fields of science and technology, with an emphasis on medical science. The article highlights the importance of a key aspect that entomological literature omits, namely the scalability of knowledge. Therefore, it is appropriate to perceive insects as accessible sources of valuable knowledge. Here a compact piece of observational data on two insect species draws attention to heterogeneous scientific domains and puts forward an idea that originally stems from entomology.

Introduction to robot-assisted surgery

Minimally invasive surgery (MIS) is a good alternative to traditional surgery if known methods are not deemed sufficiently applicable for a given human surgical intervention. The evolution of MIS leads to increased demand for automation through the use of robot-assisted surgery (RAS). Reported data on the advantages of its use are promising (Secoli *et al.* 2022). Analysis of patient data collected for patients between January 2010 – December 2017 who had undergone pulmonary resection via robotised equipment at the University Hospital of Pisa, Italy, suggests a high success rate of this surgical method for patients with non-small cell lung cancer (NSCLC) (Zirafa *et al*. 2021). The approach is also used in rectal surgery (Becker *et al*. 2016). Complete RAS setups on the market that are available in serial production are being used for various surgical interventions, such as laparoscopic MIS, including robot-assisted radical prostatectomy (RARP) (Huynh & Ahlering 2018). Intriguing that RAS is also used in neurosurgery (Secoli *et al.* 2022). Not only does this method ensure a shorter hospital stay, but also allows quicker and more efficient post-operative recovery (Huynh & Ahlering 2018). Awareness on the efficacy of RAS in minimally invasive surgery depends on the continuous collection and stringent administration of patient data concerning their scientific use (Becker *et al*. 2016). The development of this technology is also determined by the necessary upgrades to achieve better tool precision through miniaturisation and more intuitive control for the operator. Additionally, reducing production and maintenance costs is dependent upon the presence of a competitive market and the requirement for frequent patent updates of such equipment (Longmore *et al.* 2020).

Insect anatomy in surgery – overview of current advancement and the challenges

Designing and using insect cyborgs is a recent avenue of technological improvement and undoubtedly a source of intense discussions and ethical concerns over the balance between practicability and strict management of such engineering. Its application induces fears over lawful use and regulatory mechanisms to limit potential issues (Siljak *et al.* 2022). Introducing innovation through insect anatomy is rapidly evolving thanks to the widespread use of materials with specific electrostatic and suitable elastic properties, resulting in synthetic assembly of insect biomechanics (Wang *et al.* 2021). Insects can be safely regarded as reliable anatomical models to be utilised by robotics through the simulation of studied anatomical structures (Quinn & Ritzmann 2018). Therefore, it is reasonable to extend research on insect anatomy beyond their general anatomical attributes. The concept of incorporating insect anatomy in human surgical tools can potentially refer to designing specific instrumental attachments for precision surgical manipulation of tissue, based on anatomical configurations seen in insects. The growing expansion of minimally invasive surgery is inextricably related to its execution by RAS setups. This poses a challenge to achieving speedy improvement of the essential mechanical parts, very often strictly characteristic to a given RAS system, the *manipulation effectors*. Therefore, anatomical microstructures in insects with markedly flexible mechanical articulation deserve special scientific attention and can be seen as "natural" manipulation effectors.

Methods

Two insect species, *Mantispa aphavexelte* (U. Aspöck & H. Aspöck, 1994) and *Rainieria calceata* (Fallén, 1820), were subjected to visual examination *in situ* to identify distinct anatomical characters that could be considered of potential use in the context of medical applications. Observation is further backed with literary evidence that links up insect anatomical complexity with other sciences. Interpretation of the observed structures and their mechanical articulation is based on photographic evidence and notes on ethology at the time the insects were being observed (a retrospective approach to the analysis of the documentary material is applied). Documenting within the natural habitat (43°28'N, 23°56'E, Byala Slatina, Bulgaria) allowed careful inspection of how insects use the identified complex leg anatomy, with minimum disturbance i.e., the exhibited biomechanical capabilities of the two species are reported, as seen. Nikon D70s digital camera, Kenko macro extension tubes, Nikon AF Nikkor 28-80mm f/3.3~5.6 G lens and wirelessly controlled remote camera flash Nikon SB-R200 were used for taking the photographs. *Mantispa aphavexelte* was attracted to a 125W MV moth trap and *Rainieria calceata* was documented grooming on the tree bark of *Salix fragilis* from a specific survey taking place in 2021 for the above-mentioned locality, during the day (Valkov 2021, - unpublished data). Discerning *Mantispa aphavexelte* from *Mantispa styriaca* is based on Snyman *et al.* (2018).

Results

Fig. 1. *Mantispa aphavexelte*, 18.viii.2022, 23:17:55; 43°28'N, 23°56'E, Byala Slatina, Bulgaria, 125W MV moth trap. © Radoslav Valkov.

The individual is photographed next to the light source, feeding on the Diamond-back moth *Plutella xylostella* (Linnaeus, 1758) (Fig. 1).

Lateral view of key external biomechanical elements of forelegs (Fig. 2): the coxo-trochanteral joint (a) allows different angles of rotation (b), ensuring high degree of flexibility between the femur (c) and the forecoxal sulcus (d) to aid handling of prey. A brighter diagonal line on the coxa is observed (d). The notably bright forecoxal sulcus depicts a fracture of unknown origin (Fig. 2d), which does not impair the biomechanical properties of the foreleg (evidence on the notable strength of the chitinous cuticle

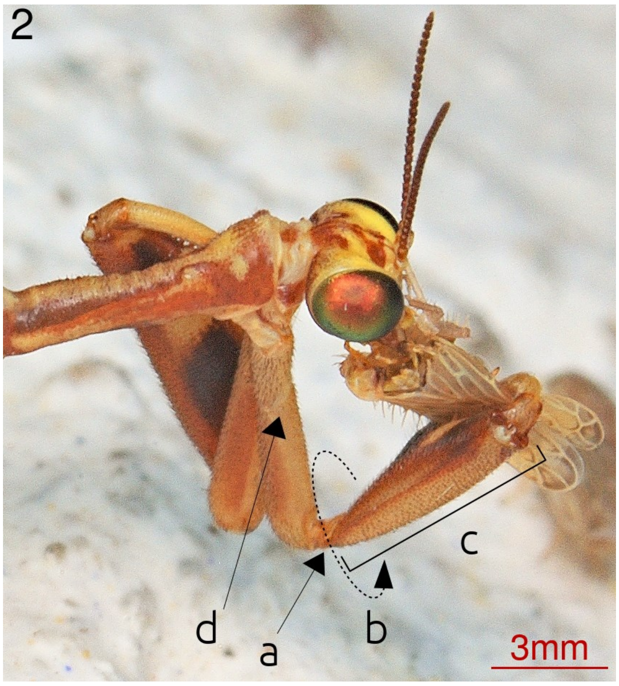

Fig. 2. *Mantispa aphavexelte*, 18.viii.2022, 23:15:16; 43°28'N, 23°56'E, Byala Slatina, Bulgaria, 125W MV moth trap. © Radoslav Valkov.

for *Mantispa aphavexelte*). The robust exoskeleton protects the muscles, which continue to function as required, even in the presence of physical harm to the leg. The observed joint rotation allows precise control over positioning food near the feeding apparatus. The ability for independent control of the forelegs during the feeding process is an important element of this potentially useful biomechanical design for surgical purposes. The insect accurately commands the rotation of the foreleg to move an object with physical dimensions within the millimetre range – a convincing analogy with a robotised microconstruction of an effector, expected to perform fine movements (Fig. 3). This observation is in line with a necessary prerequisite for improving and designing new RAS systems – miniaturisation of the manipulation effectors.

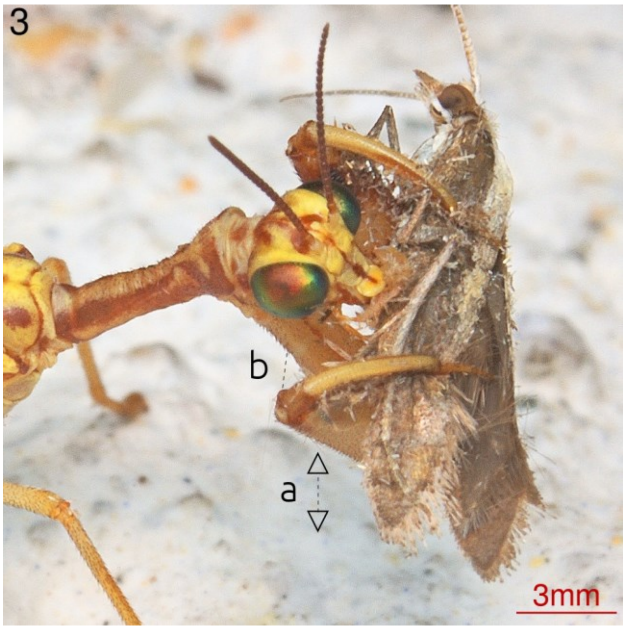

Fig. 3. *Mantispa aphavexelte*, 18.viii.2022, 23:17:55; 43°28'N, 23°56'E, Byala Slatina, Bulgaria, 125W MV moth trap. © Radoslav Valkov.

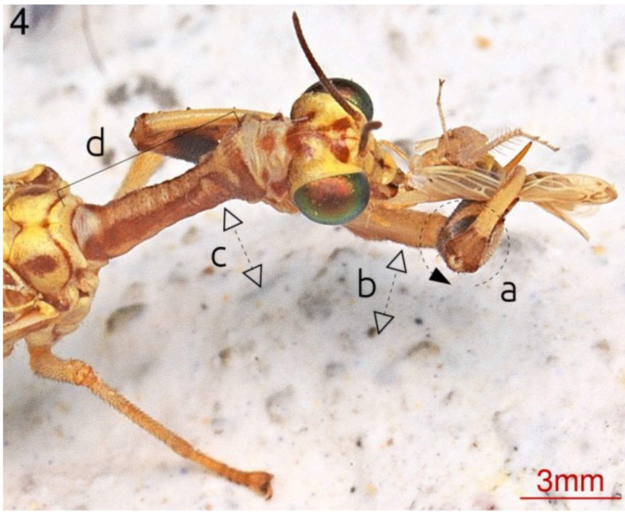

Fig. 4. *Mantispa aphavexelte*, 18.viii.2022, 23:15:52; 43°28'N, 23°56'E, Byala Slatina, Bulgaria, 125W MV moth trap. © Radoslav Valkov.

Distance between forelegs and contact surface (Fig. 4) (a) during active handling of load, increasing the angle between the coxa and the femur when feeding – an extra detail on the flexibility of the coxo-trochanteral joint. Dorsal view of key external biomechanical elements: the coxo-trochanteral joint and its rotation (a) ensure precise handing of prey; distance between the coxa and the contact surface (b); distance between the prothorax from the contact surface (c). The elongated prothorax (d) is an important support of the whole biomechanical construction of the forelegs, aided by the walking legs. This sclerotised structure is probably elongated to keep captured prey away from the body and the abdomen.

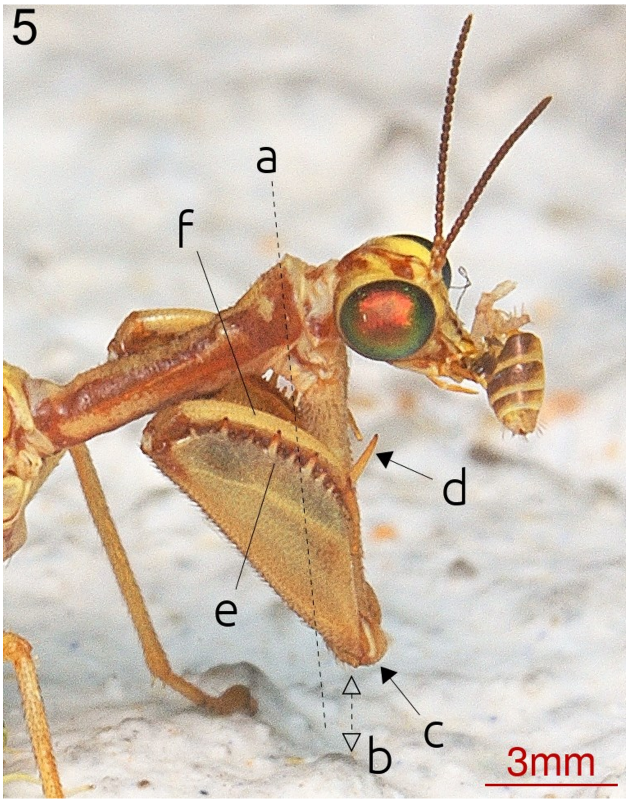

Fig. 5. *Mantispa aphavexelte*, 18.viii.2022, 23:17:12; 43°28'N, 23°56'E, Byala Slatina, Bulgaria, 125W MV moth trap. © Radoslav Valkov.

The dashed line (Fig. 5) (a) that is parallel to the coxa illustrates the position of the coxae; visible distance between the foreleg and contact surface (b); the coxotrochanteral joint (c) allows the femur to rotate backwards. Subbasal spine (d) is an additional blocking mechanism to complement the firm grip of prey pressed against the anteroventral spines (e) by the tibia (f).

Fig. 6. *Rainieria calceata*, 23.vi.2021, 11:57:17; 43°28'N, 23°56'E, Byala Slatina, Bulgaria. © Radoslav Valkov.

Note the finely regulated body posture (Fig. 6) even when the pair of legs are used for grooming. Such degree of mechanical flexibility is not present in many dipteran species.

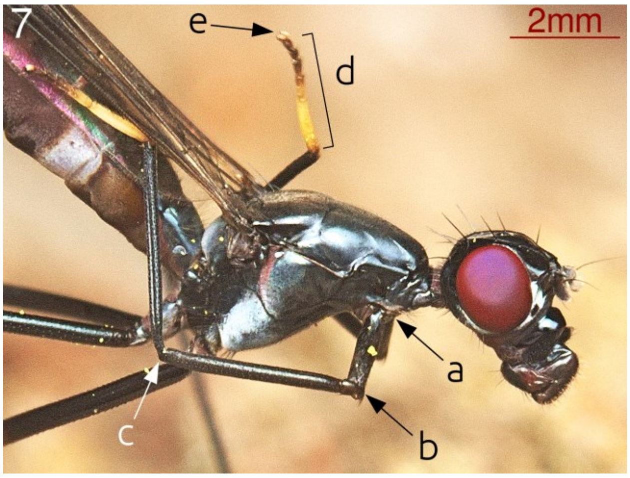

Fig. 7. *Rainieria calceata*, 23.vi.2021, 11:57:17; 43°28'N, 23°56'E, Byala Slatina, Bulgaria. © Radoslav Valkov.

Flexibility of foreleg joints (Fig. 7) (a, b, c); leg segment, which colouration is useful for identification purposes in the field (d) ends with a terminal structure – pretarsus (e).

Discussion

The requirement to miniaturise manipulation effectors, the essential hardware components in any given RAS system, is of the utmost importance because they carry out the actual surgical process and qualitatively determine the outcome of a surgical treatment. Furthermore, added multifunctionality of the effectors would allow wider spectrum of surgical capabilities. That would be possible through adapting known evolutionarily distinct mechanical properties, designed by nature, to robotics. In order to feasibly implement this complex process into surgery, availability of initial entomological data input is vital. Some layers of entomological knowledge are not instantly usable in a cross-disciplinary setting if the researched insects have not been subjected to consistent studies over time. Thus, acquiring specific anatomical detail requires species-specific concretisation. Such streamlined approach is very often absent, even within the scope of the primary source of information (entomology). Up-to-date prototyping is impossible without thoroughly assessed entomological data that is checked against criteria for adequate relatedness to a usable surgical design. Another additional potential risk to the above-mentioned circumstances is what could be defined as “unilaterality in research” i.e., presenting knowledge without explicit strategy as to how it could be qualitatively refined over time through ingenious interdisciplinary links to achieve a well-adapted practical application. Overcoming scientific challenges implies an abstract view on a given topic. The impressive biomechanics of insects could be incorporated into substantially important innovations, requiring scientific mutuality between functionally linked disciplines.

A useful surgical breakthrough, for example, inspired by an insect, is the work of Sakes *et al*. (2020) where an alternative to the known method of aspiration-based tissue transport in minimally invasive surgery is suggested. A specific anatomical feature of a wasp from the Ichneumonidae family is used as a model, more precisely the ovipositor of females. Its working principle and internal anatomy had given the authors the idea to carry out an experiment, justified by a known problem with the insufficient pressure differential in long and narrow tubes, used in aspiration-based tissue transport. The need for deep penetration into the human body requires long distances from the aspiration device to the target area of operation, causing pressure loss and consequently, unsuccessful tissue extraction. Another significant problem is the damage of healthy tissue during the process, despite the aim being exactly the opposite – speedy extraction with minimum damage. This is how Sakes *et al*. (2020) present a medically justified application of an anatomical feature, known in Ichneumonidae.

Mantispa aphavexelte belongs to the family Mantispidae (mantisflies, Order Neuroptera). Despite resembling a true mantis, the superficial similarity is due to the anatomy of the raptorial forelegs (adult Mantispidae are small, with wingspan of 15–20 mm). *Mantispa aphavexelte* is an active predator and feeds on other small insects. Being attracted by UV light at night, in such active state, it inevitably interacts with other insects, performs ambush strategy, and catches prey. This circumstance permitted documenting its feeding habits. Acquisition of food is accomplished through instant attack with the raptorial legs. Such evidently agile response of the whole biomechanical foreleg apparatus used for capturing prey implies a high level of precision during the predatory strike.

Büsse, Bäumler & Gorb discuss the internal muscular structure of an insect from the Mantispidae family – *Mastispa styriaca* (Büsse *et al*. 2021). The authors address such a finely synchronised system of articulating elements in light of an evolutionary sophisticated system to obtain food. For instance, the proposed presence of a "catapult" mechanism when the tibia is closed against the anteroventral spines on the femur when prey is attacked, suggests the legs are seen as advanced adaptations that ensure better survivorship of the insect. The authors visualise microstructures and detect differences in the material properties of articulating internal muscular elements using scan electron microscopy (SEM), micro computed tomography (µCT) and confocal laser scanning microscopy (CLSM). This comprehensive analysis on the functional morphology of *Mantispa styriaca* from 2021 generates a well-deserved fascination regarding the biomechanical evolution of *Mantispa styriaca* and Mantispidae in general. The authors highlight that even mantises (Mantodea) have not undergone thorough biomechanical analyses of the forelegs (Niederegger & Gorb 2003). Snyman & Binoy (2022) describe an unexpected instance of a dietary shift in Mantispinae, due to the well-documented presence of Mantispinae eggs near a hymenopteran nest. This finding suggests that mantisflies are evolutionary significant insects that very much deserve attention i.e., not to be overshadowed by a prevailing interest in other preferred areas of entomological research.

Studies within the scope of robotics appropriate "copying" insect muscular design due to differences in muscle arrangement between insects and vertebral organisms, unsurprisingly, in favour of insects when it comes to artificial replication of their biomechanics (Wang *et al*. 2021). All the observed mechanical activities performed by *Mantispa aphavexelte* have been photographed while the insect was positioned on a wall near the light trap. The photographic material suggests that the walking-type legs support the necessary grip to resist the weight load caused by the overall body mass of the insect, minimizing the risk of falling. The firm grip between the wall surface and the microanatomical leg structures is mediated by microscopic adhesive plates, pulvilli, present in all insect taxa (Niederegger & Gorb 2003). The mechanism of stable adherence of the legs to various surfaces, including smooth ones, ensures secure locomotion without sliding and falling (Niederegger & Gorb 2003). Attachment is accomplished through the mechanical intricacy of the pulvillus that secretes specific "adhesive"; Fowler *et al.* (2021a) researched its composition in the Seven-spotted ladybird *(Coccinella septempunctata)*. Both the complex attachment mechanisms and production of the "glue" that mediates the process, are presented through an innovative combination of tensiometric and spectroscopic methods in 2021 (Fowler *et al*. 2021b). This research cannot provide an exact answer as to whether these secretions are species-optimised and what the differences are, especially in rarely seen species of insects, like *Mantispa aphavexelte*. However, the evident stability of *Mantispa aphavexelte* on the wall surface raises questions over the strength of this "adhesive" and its specific properties. The aforementioned research on ladybirds from 2021 (Fowler *et al*. 2021b) validates the necessity of further studies of these complex structures. A potentially useful relationship with surgery is determined by the need for synthesising more advanced biomimetic adhesives, which offer surgically optimised properties i.e., safe biodegradation, reliable tissue adhesion and compatibility (no indication of tissue rejection or antagonistic physiological effects) (Mazur *et al*. 2022).

Order Diptera (True flies) includes one of the most spectacular native species for Europe from the family Micropezidae - *Rainieria calceata*. This is a rare local species for Europe, as well as for Bulgaria, with poorly studied mechanisms of dispersal and population dynamics (Valkov 2021). A small population has been documented, studied, and counted in Bulgaria in 2021 (Valkov 2021, unpublished data). The fly is strictly associated with undisturbed woody habitats where conditions for natural wood decay of old trees are present. Larvae utilise it as food; research on the presence of the fly is of particular interest due to the fact the insect is a bioindicator – both for the diversity of European fauna and for being strategically important in classifying a given habitat as ecologically valuable (Valkov 2021).

Beyond its ecological significance, not only does this understudied insect of the Bulgarian fauna exhibit remarkable mechanical flexibility but it also highlights the previous topic about adherence to smooth surfaces. Specimens from the observed population were kept and observed under controlled conditions and then released back into nature in 2021 (Valkov 2021, unpublished data). Their ability to freely walk on glass is hardly surprising, as many insects do so with ease (Walker 1993). The unusual articulation of leg joints (see Figs 6, 7) nevertheless raises further questions on the highly efficient use of the contact "adhesive". Regarding *Rainieria calceata*, visualisation of the pulvillus has not been addressed yet in scientific literature. Furthermore, the attachment mechanism of the pulvillus to a given substrate is actually a process that occurs at the nanoscale. Nanotechnology is the future of minimally invasive surgery, especially when precision is required. Studying the specificity of secreted adhesive agents by insects is yet to gain more traction. Apparently, this is a complex mechanism of attachment, based on nanotechnologies that are already available in nature. Better understanding of their function and use would allow improvement within many practically significant fields, such as molecular biology, electronics, the environment, and surgical treatment e.g., in orthopaedic surgery (for implants, correcting osteochondral defects and drug delivery in the treatment of bone cancers) (Mariappan 2019).

Conclusion

As evident from the supplied documentary material and literature, this observation correlates entomology with medical sciences. Such an idea to rationalise entomological data on external morphology for medical use has not been suggested in scientific literature to date. Current research on the morphological structures in insects and their mechanical articulation defines an intelligible method of transferring empirically authenticated evidence for biomechanical properties from entomological science to the world of modern medical RAS systems. The observed rarely encountered species of insects, *Mantispa aphavexelte* and *Rainieria calceata,* have never been considered by entomologists in terms of the practical usefulness of their leg functional morphology. The first step required to bring into action the proposed concept is to further focus on targeted exploration of mechanical micro and ultrastructures in *Mantispa aphavexelte* and *Rainieria calceata* through SEM, µCT, CLSM and other advanced methods of visualisation. Through further data collection of this kind, the above-discussed suggestions can result in actual technological development.

Order Neuroptera are of particular evolutionary interest. Snyman *et al*. (2020) remind us that Mantispidae are generally poorly researched. This further substantiates the need to subject the genus *Mantispa* to additional studies, both at an evolutionary and morphological level. In addition, their noteworthy anatomical properties are not restricted to a particular anatomical character, as seen in *Mantispa aphavexelte*. For example, the conspicuously convex shape of the pulvillus (Figs 4, 5), observed in the walking legs, as well as the presence of bifurcate claws (similar to those seen in order Coleoptera), require thorough inspection and visualisation of the respective ultrastructures. Also, studying the biomechanical function of the secreted “adhesive” and its properties for *Mantispa aphavexelte* and *Rainieria calceata* requires handling prepared specimens, as well as *in vivo* experiments.

This is where ecology, taxonomy and human medicine intersect. The pace at which such conceptual and seemingly imperceptible relationships are detected is slow. Furthermore, initiating surveys to verify the probable applicability of similar observations requires consistent dedication to studies that explore poorly researched taxa, as well as a timely response when it comes to inspecting and visualising micro and ultrastructures. Such an approach to the topic necessitates the consistent availability of technical resources to aid visual inspections. In reference to the number of ongoing studies, there is an appreciable need to put forward unconventional ideas. The limited amount of literature outlining the evolutionary sophistication of functional insect anatomy nonetheless prompts the need for further studies. Seeking odd anatomical features in rare insects of evolutionary interest is a feasible strategy to create usable cross-disciplinary links that emphasise the global role of entomology and its multifaceted significance.

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