Delicious To The Last Piece: Why Ectoparasite Prefer Human Skin

Forman Erwin Siagian,[1*] Esy Maryanti[2]

[1]Department of Parasitology and The Centre of Biomedic Research, Faculty of Medicine, Universitas Kristen Indonesia, Jakarta, Indonesia,
[2]Department of Parasitology, Faculty of Medicine, Universitas Riau, Pekanbaru, Indonesia

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ABSTRACT

The interaction of ectoparasite in correlation to its host's skin is important. The extent of interaction somewhat makes these parasites able to survive in the harsh conditon of the host's skin. Their existence mostly in the context of gaining their nutrition and perhaps continue its regeneration. Because these diseases caused by ectoparasite are easility transmitted, widespread, and the state of polyparasitism is often took place in a single vulnerable host, and significant primary and secondary morbidity and or complication occurs, which can worsen the course of the inital disease. This minireview aim to discuss about the interlinkage of some EPSD agents in correlation to its host's skin, their interaction and what makes these endoparasites able to survive in the skin in the context of gaining their nutrition.

Keywords: arthropods, vulnerable, food seeking behaviour, human louse, myasis, ectoparasite, human skin

1. INTRODUCTION

Based on its prey seeking behaviour, parasites have a tendency or predilection for certain anatomical locations in their host[1]. The causes can vary, but in general it can be said that by inhibiting certain the anatomical location, the parasite will get the greatest benefit[2]. Most often, it is in the context of getting in the context of obtaining more certain food sources. To some extent, many multicellular parasites actually pursue their potential hosts by following trails of host-emitted 'pheromenon' that attracts parasite. Host seeking is a built-in survival feature of parasite; endoparasites as well as ectoparasites such as mosquitoes and ticks. Many of these parasites use carbon dioxide (CO2), a respiration byproduct, in combination with host-specific chemicals for targetting host location[3].

The skin is the largest organ of the human body, and it serves as physical barrier and represents the first line of immunological defence against many infections, including parasitic agent[4]. As most parasites spend at least part of their existence there and often initiate a first host response[4,5]. The skin can also serve as an anatomical reservoir of ectoparasites and is a recurring theme in the transmission of arthropod-borne human illness, probably because skin penetration and followed by its invasion for enhanced preparation of

transmission to the next poor and vulnerable host, immunologicaly, is probably a significant evolutionary force[6]. However, we must kept in mind that the skin is much more than just a *port d'entrée* of entry into the host, *e.g*., vector borne malaria transmitted through the bite of female mosquito, Anopheles spp.

Ectoparasites actually are a taxonomically diverse group of micro-organisms that infiltrate the skin of human beings, and other higher ranks-animals[7]. Ectoparasitic arthropods and nematodes are indistinguishable in the way they causing disease; that such a tiny parasitic micro-organism can create skin derangements that are large enough in size that doctor or other people can easily see with unaided eye[8]. Clinical manifestations of ectoparasite invasion are often marked by intense itching, scratch related excoriation, sizeable displeasure and tenderness[9,10]. It can also caused indirect effect to the patient, *e.g*., sleep disturbance and derangement of academic/working performance[7,8,10]. From that perspective, parasitic infection also has a direct physiological cost to their hosts but may also modify the hosts's reciprocity with other individuals in selected environment[10]. This endless vicious circle is frequently found focally hyperendemic in poor and low-income countries where impoverished communities are still present in society, with a distinctly high incidence in certain prone individuals, families, households, and perhaps neighborhoods.

Apart from being an entry point for endoparasites, there are also 'real' parasites that live on the skin. Epidermal parasitic skin diseases (EPSD) are a spectrum of heterogeneous categorization of transmittable infectious pathogens in which parasite-host interactions are limited to the region of outer layer of the skin[11]. The seven major EPSD are scabies, pediculosis capitis and pediculosis corporis, pthyriasis pubis, tungiasis and hookworm-related cutaneous larva migrans and myasis due to fly larvae; all of these parasites inhabit and live on the skin and get its daily nutrients to survive[5,6]. Pediculosis (infestation by head and body lice) and scabies can be found in all human populations, in various part of the world, but in specific cases of myiasis (fly larva infestation), tungiasis (sand flea disease), and cutaneous larva migrans occur geographically in tropical and subtropical area[12]. Except for head lice and body lice, the organisms discussed in this article are never reported as vectors of pathogenic microorganisms, previously[13]. Most ectoparasites do not act as vector for their host; they are, instead, the direct causative agent of disease[7]. Eventhough the Mortality rate due to these ectoparasite is without a doubt very limited, but the effect of cumulative morbidity percentage from the direct tenderness, derangement of academic/working performance, secondary bacterial infections, and sequelae related to those ectoparasite infestations and infections[8-10,13].

This minireview aim to discuss about interaction of some EPSD agents in correlation to its host's skin, their interaction and what makes these endoparasites able to survive in the skin in the context of gaining their nutrition.

2. SKIN HOMEOSTASIS

Anatomically, the skin can be classified into three distinct compartments: (1) the epidermis, which is an avascular layer mostly composed of keratinocytes and Langerhans cells; (2) the dermis, which is highly perfused by blood and draining lymphatic vessels; and (3) the subcutaneous adipose tissue[14-16]. The structure of the skin provides an interface between the vascular and lymphatic circulations, as well as the interstitial space[15]. The lymph system is a fluid-filled anatomical compartment defined by a complex lattice of collagen bundles, found within and between tissues including the dermis. Until recently, the physiological importance and extent of the interstitium had been largely understudied, yet this compartment is very likely to be of relevance for host–pathogen interactions defining phenomena such as extravasation and sequestration of different parasites[17]. Or in a more

short and simple word to say, is to provide a good shelter for any invading ectoparasite to establish its existence[8,9].

To ensure homeostasis, actually there is always an extensive crosstalk happened between epithelial, stromal, and immune cells[7,8,18]. Unfortunately, most parasites have developed mechanisms to evade detection and successfully establish an infection either in the skin itself or elsewhere in the host[8,18].

3. RESULTS AND DISCUSSION HOW DO PARASITES SURVIVE IN THEIR HOSTS?

Parasites vary in the number of hosts they need to survive, a phenomenon which demonstrated through the complexity of their life cycle[19]. Ecological condition combined with the host's behaviour favoured its transmission, While definite parasites need only a single host, other type of parasites use numerous hosts to veritable their complex life cycles[20].

Parasitism is a constant confrontation for survival between the parasite and its host; whether the parasite lives inside or on the surface of the host's vulnerable body[21,22]. Parasites rely on their host for nourishment as their source of nutrition and also for shelter to ensure its survival without compromising the host's immune system alertness[2] . they must make sure the host is not demolish until they are reaching the phase of readiness to proceed to the next vulnerable host. On the other hand, the hosts themselves must preserve themselves from threats and dangers caused by direct activity of the parasite or secondary due to parasite's metabolite products and or immune arousal. To protect themselves, the hosts continuously defiance any *corpus alienum* parasitic organisms by producing harsh and unfavorable *milleu*[23]. The host will make an effort to minimize the parasites access to nutrients, systematically starving them to death, or even will directly ambush the parasites with the arousal of suffcient immune responses[23]. In order to succesfully maintaining their lives in such a difficult habitat, each parasite has developed different survival strategies[24].

As parasites directly harm their hosts, the host may respond with development of counteradapt mechanism that diminished the fitness costs of parasitism[22]. But over millions of years of evolution, parasites have acquired lots of unique but useful properties to help them adapt or counter adapt to specific conditioned environments built by their hosts[25]. Some examples of those features are as follows:

1. The ability to evade or modify the host's immune responses. Each type of parasite, as long as it is in the body of its host, will definitely experience persistent exposure and even challenged by the host's immune armamentarium as part of their natural defenses and also other unfavorable conditions, such as internalization by host's macrophage or other type of phagocytic cells for small intracellular parasitic organism[26-28]. Nutrient, including mineral, limitation and deprivation also a milleu conditioned by a coordinated set of actions from cells, tissues and even host organs as a response to parasite invasion[24,29]. Parasites have developed unique ways to respond to such attacks by several types of immune cells that belongs to their hosts. For example, the formation of parasitophorous vacuole (PV) in host cells (HC) harbouring different intracellular protozoan parasites during internalization by host cells, *e.g.*, in cases of the trypanosomatid (protozoan) parasites infection, *Trypanosoma cruzi* and *Leishmania* spp. that causes Chagas disease and Leishmaniasis. Other example respectively, is the *Plasmodium* species, which cause malaria in humans, which developed their ability to

shift their ‘macros’ appearances by switching their surface proteins and thereby avoiding recognition by the host’s immune system[30]. Other parasites have acquired the ability to directly inhibit activation of certain cells and or making the condition is not favorable to the host[31-33].

2. Modifying their reproductive game plan. Parasites have evolved host specialization, in which they live and reproduce within the milleu of one particular host, actually this option is a two sided sword because eventhough this strategy allows the parasite to be more established inside that particular host, the host specialization also has several limitations for the parasite, including reducing the parasite’s chances of finding equivalent mate[19,34]. Parasitic organisms have evolved different ways to solve this problem. For the blood flukes, *Schistosoma* spp., once the male meets female worm inside their host, they will modify their existence, from initially single and solitary they then stick with each other for as long as they are alive, unless another male is present nearby which allow sexual selection via male-male competition and female choice for large males[35]. Another example are the hermaphrodite tapeworms, where both reproductive organs are installed on the same worm, so that the urgency of finding a tantamount mate is not necessary,

3. Limiting potential harm to the host; because no matter what parasite invade their hosts, they still need at least nutrition for their own fitness, and this might caused problem for their host. If this activity is too active, the stake is the host's life[2]. So, from the point of view of the parasites, it is important to limit the harm they cause, so that the host stays alive for a long period of time. In response to this situation, this clever parasite able to dictate their host’s reaction named tolerance. Classically, a reaction norm defines host tolerance because it depicts the change in host fitness as a function of parasite load, where a shallow negative slope indicates that host fitness slowly deteriorates as parasite load increases (*i.e*., high tolerance) [36]. Three further novel advancements in the tolerance field are the appreciation of the role of (1) extrinsic, environmental factors on tolerance, (2) host tolerance in multi-host–parasite systems and (3) individual-based approaches to tolerance measures[36] .

So it is clear that the parasite develops several different strategies to maintain its survival in the body of its host. This strategies are not uniform for all parasite, each develop their own way of surviving from the potentially dangerous environment and maintaining their existence and well-being. Further we are going to discuss about how skin as a specific niche for ectoparasite contributes for their source of nutrition and shelter.

3.1 skin give food and shelter for ectoparasite

The skin as an organ, actually is relatively open and exposed to outer world, directly. Arthropods are the most commonly encountered parasites in the skin and subcutaneous tissues and in this group there are a number of parasitic organisms, namely: *Sarcoptes scabei*, *Demodex* species, *Tunga penetrans*, and myiasis-causing fly larvae[37].

If we focus on the context of EPSD, their host’s skin provides a number of important resources for their well-being. Most vitally once again, the host supplies a guaranteed supply of good quality of nutrient for the life of the parasite, no matter if they exist temporarily or permanently. Debris of the skin, sweat, blood, other kind of superficial dead cells are some example of source of nutrition made available by their human host[38].

Beside food, human as host also provide suitable environment for the parasite’s life sustainability[39]. The host’s body actually and unintentionally provide the condition is

suitable for parasite to reach its optimum development, in number and in size or proportion[39,40]. In those environment, in which ectoparasites live, generating warmth, moisture and within the skin, or hair or even nail (in the context of fungus) and these three organs give these parasites, to some extent, protection from the harsh environment[40]. in other context, the host's even provide a safe first class transportation for the parasite, and by facilitating this, it allows them to spread even to far away places from the initial infection. and perhaps a perfect site at which to mate, and in many cases, the means of transmission from host to host[41,42].

3.2 how the parasite feed

Sarcoptes scabies. Scabies mites consume cell liquids and dead skin cells from their hosts[43-45]. Although infestation of multiple mites is possible, acrually in terms of its virulence, they do not evince any social or colonial etiquette. *Mr. Sarcoptes scabiei* only generate burrows in order to continue the descent by meeting his perfect mate, and are generally believed that it only found wandering and feeding on the host's skin[45,46]. Once they have copulated, *Mrs. Sarcoptes scabiei* use their built-in mouthparts to consume the remains of dead tissue in an attempt to prepare itself for regeneration; and while doing that it gradually generates the extension of their molting tunnels in a characteristically serpentine pattern[45,47]. On her odyssey, *Mrs. Sarcoptes scabiei* also helps lay eggs along the way in the direction of its motion[48]. Some variants of scabies mites are capable of detecting particular odor and thermal; these two considered as stimuli for their well-being, enabling them to find a host again quickly should they be removed[45-48]. They may also be attracted to lipid compounds found on host's skin[46]. Scabies mites ingest cell liquids and skin cells from their hosts[45-48].

Data acquired from the extensive study of *Sarcoptes scabiei var. Canis* provided us information about this variant's inability to sorb sufficient proportion of water vapor from unsaturated air in order to compensate for water loss in spite of an active uptake mechanism, both actively or passively[46]. The maintenance effort of balancing the water needs in this mite is supported primarily by its preference position at the dry stratum corneum–stratum lucidum and stratum granulosum interface; and this is done by its ingestion of intercellular fluid that oozes into the burrow or around its mouth portion.

Water loss rate constants for *Mrs. Sarcoptes scabiei*. Rate constants for uptake of tritiated water and approach of equilibrium tritiated body water content for both sexes (males and females) were independent of external relative humidity. Fast water loss and uptake rates, uptake rate constants independent of relative humidity, and the observation that isolated mites produce an external fluid secretion suggest that these mites, during its lifetime, actively attain water byconsuming a hygroscopic solution provided by the host. However, actually this action is not completely appropriate to compensate its water loss[46].

Pediculus spp and *Pthyrus pubis*. *Pediculus humanus*, the human body louse, is widespread where overcrowding and lack of hygiene are present, in areas of the world affected by poverty, war, famine and presence of refugees. It has recently been considered re-emerging among homeless populations in developed countries[49]. Pediculus humanus is a vector of highly relevant human pathogens[51]. Pthyriasis is considered as sexually transmitted disease[52].

These louse has a built-in armamentarium or equipment, which supports them to survive in unfavorable conditions on the surface of the host's body[50]. There are at least three elements of the body that facilitate its existence, namely (1) long and narrow sucking mouth

parts covered within the head, (2) short antennae, and (3) three pairs of clawed legs adapted for holding and grabbing the host's hair[53].

A louse gets its nutrient by way of penetrating the host's skin, reaching the superficial vessels of the skin and sucking blood, while doing so its also simultaneously injecting its saliva which contain vasodilatory and anticoagulation properties into the host[54,55]. Human louse are obligate ectoparasites. They live off of the blood of humans[50]. They have specially designed mouth parts for piercing the skin of humans and retrieving the blood that is present[51,53]. It is very interesting to seek for the parasite's basic nutrition daily need, and wether this also affect the parasite's host seeking pattern[50-55].

Myiasis (fly larva infestation). Beside their role as potential vector,the adult flies are not true parasitic, but when they lay their eggs in open wounds and these hatch into their larval stage (also known as maggots or grubs), the larvae feed on live or necrotic tissue, causing myiasis to develop[56]. They may also be ingested or enter through other body apertures[56,57]. Myiasis is defined as the infestation of live vertebrates (humans and/or animals) with dipterous larvae. In mammals (including humans), dipterous larvae can feed on the host's living or dead tissue, liquid body substance, or ingested food and cause a broad range of infestations depending on the body location and the relationship of the larvae with the host[57]. By knowing the basic daily need of this larvae, perhaps in the future this can be an option to do the wound debridement in an open lesion, without compromising the safety and efficacy.

4. CONCLUSION

We summarize the current knowledge on interaction of EPSD agents in correlation to its host's skin, their interaction and what makes these ectoparasites able to survive in the skin in the context of gaining their nutrition. Because these diseases are widespread, and the condition of polyparasitism is often found, and significant primary and secondary morbidity (complication) occurs.

COMPETING INTERESTS

"Authors have declared that no competing interests exist.".

AUTHORS' CONTRIBUTIONS

Authors may use the following wordings for this section: " 'Author FES & EM' both designed the theme, performed the literature searching, wrote the first draft of the manuscript, then managed the analyses and re-checking the draft. All authors read and approved the final manuscript."

CONSENT (WHERE EVER APPLICABLE)

No necessary

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REFERENCES

1. Gang SS, Hallem EA. Mechanisms of host seeking by parasitic nematodes. Mol Biochem Parasitol. 2016;208(1):23-32. doi: 10.1016/j.molbiopara.2016.05.007

2. King IL, Li Y. Host-Parasite Interactions Promote Disease Tolerance to Intestinal Helminth Infection. Front Immunol. 2018;9:2128. doi: 10.3389/fimmu.2018.02128.

3. Chaisson KE, Hallem EA. Chemosensory behaviors of parasites. Trends Parasitol. 2012;28(10):427-36. doi: 10.1016/j.pt.2012.07.004.

4. Janeway CA Jr, Travers P, Walport M, et al. Immunobiology: The Immune System in Health and Disease. 5th edition. New York: Garland Science; 2001. The front line of host defense. Available from: https://www.ncbi.nlm.nih.gov/books/NBK27105/

5. Abdallah F, Mijouin L, Pichon C. Skin Immune Landscape: Inside and Outside the Organism. Mediators Inflamm. 2017;2017:5095293. doi: 10.1155/2017/5095293.

6. Capewell P, Cren-Travaillé C, Marchesi F, Johnston P, Clucas C, Benson RA, et al. The skin is a significant but overlooked anatomical reservoir for vector-borne African trypanosomes. Elife. 2016;5:e17716. doi: 10.7554/eLife.17716.

7. Kupfer TR, Fessler DMT. Ectoparasite defence in humans: relationships to pathogen avoidance and clinical implications. Philos Trans R Soc Lond B Biol Sci. 2018;373(1751):20170207. doi: 10.1098/rstb.2017.0207.

8. Schmid-Hempel P. Immune defence, parasite evasion strategies and their relevance for 'macroscopic phenomena' such as virulence. Philos Trans R Soc Lond B Biol Sci. 2009;364(1513):85-98. doi: 10.1098/rstb.2008.0157.

9. Heukelbach J, Feldmeier H. Ectoparasites--the underestimated realm. Lancet. 2004;363(9412):889-91. doi: 10.1016/S0140-6736(04)15738-3.

10. Dunn AM, Torchin ME. Hatcher MJ, Kotanen PM, Blumenthal DM, Byers JE, et al. Indirect effects of parasites in invasions. Functional Ecology, 2012;26: 1262-74.

11. Feldmeier H, Heukelbach J. Epidermal parasitic skin diseases: a neglected category of poverty-associated plagues. Bull World Health Organ. 2009; 87(2):152-9. doi: 10.2471/blt.07.047308.

12. Salkeld DJ, Trivedi M, Schwarzkopf L. Parasite loads are higher in the tropics: temperate to tropical variation in a single host-parasite system. Ecography, 2008; 31: 538-44.

13. Badiaga S, Brouqui P. Human louse-transmitted infectious diseases. Clin Microbiol Infect. 2012;18(4):332-7. doi: 10.1111/j.1469-0691.2012.03778.x.

14. De Niz M, Meehan GR, Brancucci NMB, Marti M, Rotureau B, Figueiredo LM, et al. Intravital imaging of host-parasite interactions in skin and adipose tissues. Cell Microbiol. 2019;21(5):e13023. doi: 10.1111/cmi.13023. Epub 2019 Apr 3. PMID: 30825872; PMCID: PMC6590052.

15. Stewart RH. A Modern View of the Interstitial Space in Health and Disease. Front Vet Sci. 2020;7:609583. doi: 10.3389/fvets.2020.609583.

16. Ryan T. The ageing of the blood supply and the lymphatic drainage of the skin. Micron. 2004;35(3):161-71. doi: 10.1016/j.micron.2003.11.010.

17. Benias PC, Wells RG, Sackey-Aboagye B. Structure and Distribution of an Unrecognized Interstitium in Human Tissues. Sci Rep 2018;8: 4947. https://doi.org/10.1038/s41598-018-23062-6

18. Chulanetra M, Chaicumpa W. Revisiting the Mechanisms of Immune Evasion Employed by Human Parasites. Front Cell Infect Microbiol. 2021;11:702125. doi: 10.3389/fcimb.2021.702125.

19. Auld S, Tinsley M. The evolutionary ecology of complex lifecycle parasites: linking phenomena with mechanisms. Heredity, 2015;114:125–32. https://doi.org/10.1038/hdy.2014.84

20. Hawley DM, Gibson AK, Townsend AK, Craft ME, Stephenson JF. Bidirectional interactions between host social behaviour and parasites arise through ecological and evolutionary processes. Parasitology. Cambridge University Press; 2021; 148(3):274–88.

21. Rigaud T, Marie-Jeanne PM, Brown MJF. Parasite and host assemblages: embracing the reality will improve our knowledge of parasite transmission and virulence. Proc. R. Soc. B. 2010; 277:3693–702. http://doi.org/10.1098/rspb.2010.1163

22. Caljon G, De Muylder G, Durnez L, Jennes W, Vanaerschot W, Dujardin JC. Alice in microbes' land: adaptations and counter-adaptations of vector-borne parasitic protozoa and their hosts. FEMS microbiology reviews 2016; 40(5): 664-85

23. Hart BL. Behavioural defense against parasites: interaction with parasite invasiveness. Parasitology. Cambridge University Press; 1994; 109(S1):S139–51.

24. Zuzarte-Luís V, Mota MM. Parasite Sensing of Host Nutrients and Environmental Cues. Cell Host Microbe. 2018;23(6):749-58. doi: 10.1016/j.chom.2018.05.018.

25. Perry GH. Parasites and human evolution. Evol Anthropol. 2014;23(6):218-28. doi: 10.1002/evan.21427. PMID: 25627083.

26. de Menezes JP, Saraiva EM, da Rocha-Azevedo B. The site of the bite: Leishmania interaction with macrophages, neutrophils and the extracellular matrix in the dermis. Parasites Vectors, 2016; 9: 264. https://doi.org/10.1186/s13071-016-1540-3

27. Batista MF, Nájera CA, Meneghelli I, Bahia D. The Parasitic Intracellular Lifestyle of Trypanosomatids: Parasitophorous Vacuole Development and Survival. Front Cell Dev Biol. 2020;8:396. doi: 10.3389/fcell.2020.00396. PMID: 32587854; PMCID: PMC7297907.

28. Nelson BN, Hawkins AN, Wozniak KL. Pulmonary Macrophage and Dendritic Cell Responses to Cryptococcus neoformans. Front Cell Infect Microbiol. 2020;10:37. doi: 10.3389/fcimb.2020.00037. PMID: 32117810; PMCID: PMC7026008.

29. Pulkkinen K, Wojewodzic MW, Hessen DO. Phosphorus limitation enhances parasite impact: feedback effects at the population level. BMC Ecol. 2014;14:29. doi: 10.1186/s12898-014-0029-1. PMID: 25366521; PMCID: PMC4223164

30. Beeson JG, Drew DR, Boyle MJ, Feng G, Fowkes FJ, Richards JS. Merozoite surface proteins in red blood cell invasion, immunity and vaccines against malaria. FEMS Microbiol Rev. 2016;40(3):343-72. doi: 10.1093/femsre/fuw001.

31. Nunes MP, Fortes B, Silva-Filho JL, Terra-Granado E, Santos L, et al. Inhibitory Effects of Trypanosoma cruzi Sialoglycoproteins on CD4+ T Cells Are Associated with Increased Susceptibility to Infection. PLOS ONE,2013; 8(10): e77568. https://doi.org/10.1371/journal.pone.0077568

32. Maizels RM. Parasite immunomodulation and polymorphisms of the immune system. J Biol 2009;8:62. https://doi.org/10.1186/jbiol166

33. Sorobetea D, Svensson-Frej M, Grencis R. Immunity to gastrointestinal nematode infections. Mucosal Immunol 2018;11: 304–315. https://doi.org/10.1038/mi.2017.113

34. de Medeiros, B.A.S., Farrell, B.D. Evaluating insect-host interactions as a driver of species divergence in palm flower weevils. Commun Biol 2020;3: 749. https://doi.org/10.1038/s42003-020-01482-3

35. Steinauer ML. The sex lives of parasites: investigating the mating system and mechanisms of sexual selection of the human pathogen Schistosoma mansoni. Int J Parasitol. 2009; 39(10):1157-63. doi: 10.1016/j.ijpara.2009.02.019.

36. Kutzer MAM, Armitage SAO. Maximising fitness in the face of parasites: a review of host tolerance. Zoology 2016;119 (4): 281-9

37. Norgan AP, Pritt BS. Parasitic Infections of the Skin and Subcutaneous Tissues. Adv Anat Pathol. 2018;25(2):106-123. doi: 10.1097/PAP.0000000000000183.

38. Dagrosa AT, Elston DM. What's eating you? head lice (Pediculus humanus capitis). Cutis. 2017;100(6):389-392.

39. Rohr, JR, Barrett, CB, Civitello DJ. Emerging human infectious diseases and the links to global food production. Nat Sustain 2019;2: 445–6. https://doi.org/10.1038/s41893-019-0293-3

40. Doehl JSP, Bright Z, Dey S. Skin parasite landscape determines host infectiousness in visceral leishmaniasis. Nat Commun 2017;8:57. https://doi.org/10.1038

41. Goodman BA, Johnson PTJ. Disease and the extended phenotype: parasites control host performance and survival through induced changes in body plan. PLOS ONE 2011;6(5): e20193. https://doi.org/10.1371/journal.pone.0020193

42. Brown SP, Renaud F, Guégan JF. Thomas F. Evolution of trophic transmission in parasites: the need to reach a mating place?. Journal of Evolutionary Biology, 2001;14: 815-20. https://doi.org/10.1046/j.1420-9101.2001.00318.x

43. Cao B, Guiton P. Important Human Parasites of the Tropics. Frontiers for Young Minds. 2018;6. Doi: 10.3389/frym.2018.00058.

44. Cardoso AEC, Cardoso AEO, Talhari C, Santos M. Update on parasitic dermatoses. An Bras Dermatol. 2020;95(1):1-14. doi: 10.1016/j.abd.2019.12.001.

45. Arlian LG, Vyszenski-Moher DL, Pole MJ. Survival of adults and development stages of Sarcoptes scabiei var. canis when off the host. Exp Appl Acarol. 1989;6(3):181-7. doi: 10.1007/BF01193978. PMID: 2496958.

46. Arlian LG, Runyan RA, Vyszenski-Moher DL. Water Balance and Nutrient Procurement of Sarcoptes scabiei var. canis (Acari: Sarcoptidae), Journal of Medical Entomology, 1988; 25(1): 64–8, https://doi.org/10.1093/jmedent/25.1.64

47. Chandler DJ, Fuller LC. A Review of Scabies: an Infestation More Than Skin Deep. Dermatology. 2019;235(2):79-90. PubMed PMID: 30544123.

48. Levi A, Ingber A, Enk CD, Mumcuoglu KY. Detection of living Sarcoptes scabiei larvae by reflectance mode confocal microscopy in the skin of a patient with crusted scabies, J. Biomed. Opt. 2012; 17(6): 060503. https://doi.org/10.1117/1.JBO.17.6.060503

49. De Liberato C, Magliano A, Romiti F. Report of the human body louse (Pediculus humanus) from clothes sold in a market in central Italy. Parasites Vectors, 2019;12, 201. https://doi.org/10.1186/s13071-019-3458-z

50. Amanzougaghene N, Fenollar F, Raoult D, Mediannikov O. Where Are We With Human Lice? A Review of the Current State of Knowledge. Front Cell Infect Microbiol. 2020 Jan 21;9:474. doi: 10.3389/fcimb.2019.00474. PMID: 32039050; PMCID: PMC6990135.

51. Raoult D, Roux V. The body louse as a vector of reemerging human diseases. Clin Infect Dis. 1999;29(4):888-911. doi: 10.1086/520454. PMID: 10589908.

52. Anderson AL, Chaney E. Pubic lice (Pthirus pubis): history, biology and treatment vs. knowledge and beliefs of US college students. Int J Environ Res Public Health. 2009 Feb;6(2):592-600. doi: 10.3390/ijerph6020592.

53. Bonilla DL, Durden LA, Eremeeva ME, Dasch GA. The biology and taxonomy of head and body lice--implications for louse-borne disease prevention. PLoS Pathog. 2013;9(11):e1003724. doi: 10.1371/journal.ppat.1003724.

54. Jones D. The neglected saliva: medically important toxins in the saliva of human lice. Parasitology. 1998;116 Suppl:S73-81. doi: 10.1017/s0031182000084961. PMID: 9695112.

55. Fontaine A, Diouf I, Bakkali N. Implication of haematophagous arthropod salivary proteins in host-vector interactions. Parasites Vectors 2011;4: 187. https://doi.org/10.1186/1756-3305-4-187

56. Hall M, Wall R. Myiasis of humans and domestic animals. Adv Parasitol. 1995;35:257-334. doi: 10.1016/s0065-308x(08)60073-1. PMID: 7709854.

57. Francesconi F, Lupi O. Myiasis. Clin Microbiol Rev. 2012;25(1):79-105. doi: 10.1128/CMR.00010-11. PMID: 22232372; PMCID: PMC3255963.