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1 **Linking microbiota composition with antimalarial antibody response**

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17

18 **Abstract**

19 Microbiota composition recently arose as a factor correlating with malaria infection. Mandal *et al.*  
20 showed via cecal transplant and antibacterial treatment that the mouse microbiota modulates  
21 parasitemia by affecting spleen germinal centers where B-cells are matured. They further  
22 identified correlations between microbiota composition and malaria severity in Ugandan children.

23

24 In mammals, the gut microbiota shapes both mucosal and systemic immunity, impacting the  
25 outcome of infections, even those that take place distally from the gut. Malaria infections  
26 represent an interesting working model on this regard, as the causing *Plasmodium* parasites  
27 primarily infect the liver and blood of the mammalian host, without colonizing the gastrointestinal  
28 lumen. *Plasmodium* parasites are transmitted by *Anopheles* mosquitoes. After being introduced  
29 into the skin during a bite, parasites travel to the liver where they multiply inside hepatocytes. The  
30 new progeny released in the bloodstream will then cyclically infect and proliferate in red blood  
31 cells. Antibodies against *Plasmodium* parasites, which are produced by germinal centers in the  
32 spleen, are critical to control infection.

33 *Plasmodium* infection has recently been found to correlate with microbiota composition in  
34 mice [1,2]. These correlations were linked to the presence of specific bacteria [1] or to a gut  
35 microbiota-dependent production of *Plasmodium*-specific antibodies in germinal center immune  
36 cells [3]. To further investigate these associations, Mandal and collaborators took advantage of a  
37 mouse model (strain C57BL/6) purchased from two different vendors (Tac, for *Taconic Biosciences*,  
38 and CR, for *Charles River Laboratories*; [4]). These mice represent a unique system to study  
39 associations between gut microbiota composition and malaria infection, as they are characterized  
40 by a distinct response to *Plasmodium yoelii* 17XNL, with Tac mice efficiently restricting parasitemia  
41 and CR being more permissive [2]. Using cecal transplants, Mandal *et al.* showed that the CR  
42 enterotype (i.e. microbiota composition) “dominates” over the Tac one: after cecal transplants  
43 from CR to Tac, mice shift from a Tac to a CR enterotype, but after a transplant from Tac to CR,  
44 mice keep a CR-enterotype. Accordingly, Tac mice receiving CR caecum content exhibit higher  
45 parasitemia, but not vice versa (**Figure 1A**).

46 Mandal and colleagues then perturbed the microbiota by providing mice with five  
47 alternative antibiotic treatments. They observed a strong decrease in parasite burden when

48 treating CR susceptible mice with these antibiotics, which links the bacterial component of the gut  
49 microbiota to *P. yoelii* infection. Using vancomycin, an antibiotic that does not cross the gut  
50 barrier, at different time points prior to or after *Plasmodium* infection, they linked microbiota  
51 perturbation with efficiency of parasite clearance. First, they found that antibiotic treatment  
52 several weeks before infection reduced *P. yoelii* parasitemia in CR mice and protected animals  
53 against experimental cerebral malaria upon subsequent *Plasmodium berghei* ANKA infection.  
54 Second, treatment 7 days after infection was still able to significantly reduce *P. yoelii* infection  
55 burden, indicating that microbiota perturbation can rapidly influence defense against infection.  
56 Finally, to investigate connections between microbiota and immunity, the authors examined  
57 germinal center reactions in CR mice treated with vancomycin. They found that vancomycin  
58 treatment induced the production of CD4+ follicular helper T cells and germinal center B cells.  
59 Disruption of germinal center functions mitigated the effect of antibiotic-treatment on immune  
60 cells and on parasitemia (**Figure 1B**).

61 The authors also assessed correlations between malaria infection and microbiota  
62 interactions in a small cohort of children in Uganda. They found different bacteria compositions in  
63 the asymptomatic *Plasmodium falciparum*-infected patients, the infected with severe malarial  
64 anemia and the non-infected children. They did not identify any bacteria that appear protective  
65 against severity, but rather found that the frequency of specific bacteria, such as *Flavonifractor*  
66 *plautii*, *Escherichia coli* and *Faecalibacterium prausnitzii* positively correlated with severe malaria.  
67 This profiling allowed them to build a supervised machine learning model that predicted *P.*  
68 *falciparum* status with 74% accuracy.

69 This work sheds new light into the interplay between microbiota and immune system. It  
70 demonstrates that bacteria, rather than fungal, eukaryotic, or viral components of the microbiota,  
71 are responsible for the observed effects on parasitemia in mice, as antibacterial treatment fully

72 recapitulates the impact of cecal transplant. By providing an intriguing example of antibiotic  
73 treatment strengthening the immune system, this study may have important implications in  
74 humans, especially in malaria-endemic regions where antibiotics are often prescribed to treat  
75 non-specific febrile symptoms or used as self-medication [5,6]. An association between malaria  
76 infection and microbiota composition in humans has been described in few independent studies  
77 [1,7]. Such correlations may be explained both by an influence of specific bacteria on host  
78 immunity affecting malaria infection [1], as highlighted in Mandal *et al.*'s study, and by the  
79 alteration of host physiology by *Plasmodium*, promoting colonization by specific bacteria [8,9].

80         On an experimental perspective, this work further highlights that besides host and parasite  
81 genetics, the host microbiota can strongly influence the outcome of malaria infections in the  
82 laboratory. Microbiota, which is directly related to host diet and nutrition, should be monitored as  
83 an additional experimental variable to achieve reproducible and solid results across replicates and  
84 laboratories [10]. Reproducibility could be improved by using experimental models with a known  
85 microbiota composition, using for instance germ-free mice recolonized with specific microbiota  
86 communities.

87         Our understanding of interactions between gut microbiota and malaria severity is still  
88 preliminary and further studies are needed to understand the mechanisms behind these results,  
89 to identify bacterial species responsible for these observations and to assess whether these results  
90 could be recapitulated in other mouse models or with other parasites. While we are far from  
91 discovering the “magic pill” that will make us resistant to infectious diseases, such advances in the  
92 study of microbiota-immune system crosstalk may eventually lead to the development of  
93 probiotics as living therapeutics for improving human health, even when dealing with pathogens  
94 that never infect the gut. This also opens perspectives to personalized medicine, which considers  
95 each patient's identity in terms of genome, proteome and metabolism, and which may also

96 include the microbiota composition as an important parameter to monitor and to link to specific  
97 medical conditions.

98

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103

## 104 **Declaration of Interests**

105 The authors declare no competing interests.

106

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108

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131 **Figure 1. The gut bacterial microbiota modulates spleen germinal center reactions during**

132 ***Plasmodium yoelii* infections. (A)** Gut microbiota composition differs in mice purchased from two

133 distinct vendors (CR, Charles Rivers Laboratories; Tac, Taconic Biosciences) and correlates with

134 different ability to control parasitemia during *P. yoelii* infection (CR: susceptible to

135 hyperparasitemia; Tac: resistant to hyperparasitemia). Fecal transplants can induce the CR

136 phenotype in Tac mice but not vice versa. **(B)** An antibacterial treatment reduces parasite burden

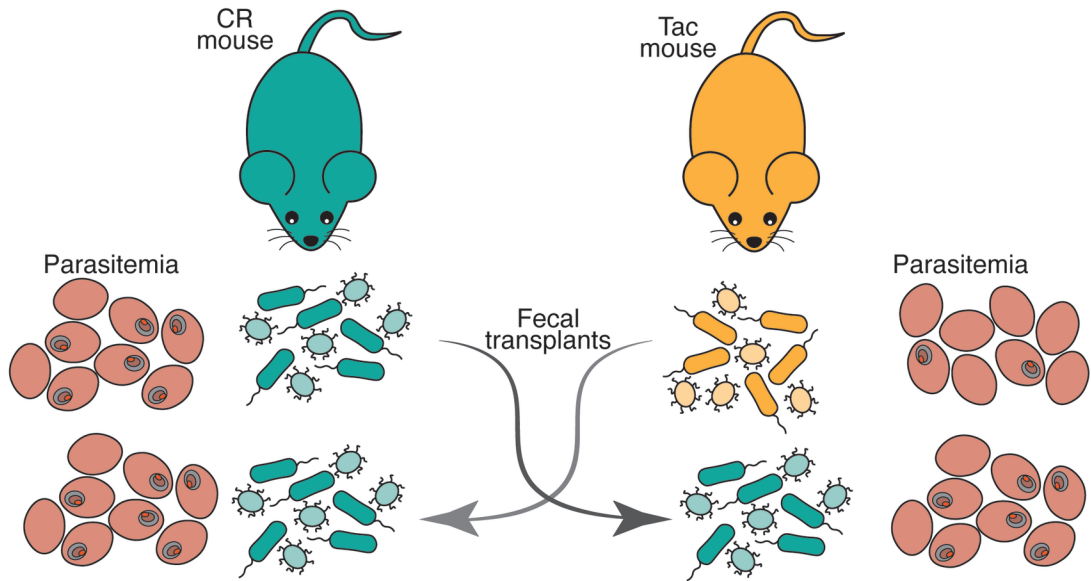
137 and induces the production of germinal center B cells and CD4+ follicular helper T cells. Disruption

138 of germinal center functions mitigates the effect of antibiotic treatment on immune cells and on

139 parasitemia.

140

A



B

