Novel approaches involving mosquito centred models for the dynamics and transmission of malaria in human and mosquito populations

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Mathematical models have extended our understanding of the biology of disease vectors as well as transmission dynamics of the diseases that vectors carry. One such indirectly transmitted infectious disease of humans, for which mathematical models abound, is the malaria disease that is caused by a parasitic organism of the genus Plasmodium and is transmitted from human to human by the female mosquito of the genus Anopheles, when it interacts with humans; having as it does, a blood sucking habit. The female Anopheles mosquito seeks to bite humans (and other vertebrate hosts) to harvest blood from which she derives proteins for the maturation of her eggs. This intrinsic behavioural characteristic forces the female Anopheles mosquito to target, locate and interact with humans at strategic times in its life cycle. For example, for a female Anopheles mosquito to lay a viable batch of eggs, she must first be fertilized by a male, and thereafter seek and ingest (human) vertebrate blood, rests for the blood to be digested and then seek and locate a suitable breeding site to lay her eggs. It is believed that characteristic behaviours of the mosquito such as mating, questing for blood meals, seeking for a breeding site and oviposition are governed by internal and external cues, and that though the type of response to the cues is mostly genetically determined, there is some plasticity that is governed by physiological conditions and external stimuli. The cycle of taking a blood meal, resting, laying eggs (oviposition) and then going for a blood meal again is called a gonotrophic cycle. The malaria parasite has exploited the mosquitos blood-feeding habit and has adapted its life cycle so that part of it is in the human and the other part in the mosquito. However, to be able to serve as an efficient vector for the malaria parasite, the Anopheles sp. mosquito must, during its entire life, attempt to and successfully take blood from more than one human. This behavioural characteristic has important consequences for malaria transmission as the mosquitoes that transmit malaria must have had multiple blood meals and also contracted the malaria parasite during one of its earlier sorties. As mosquitoes interact with humans, the variability in the human population can arise from the fact that mosquitoes carry deadly infections that affect the size of the human population over time. On the other hand, efficient human activities geared at controlling mosquitoes also affect the size of the mosquitos population over time.

Now, most of the earlier malaria models treat the mosquito population density as a constant parameter in the analyses and, even when the mosquito population is not constant; the earlier models have often neglected the fact that there is a net reproductive gain accruing to the mosquitos population size as a consequence of its successful interaction with humans. Therefore, in addition to accounting for the behavioural traits of the mosquito as well as all those interactions with humans that can lead to the transfer of the infection from one human to the other, it is necessary to also quantify the net reproductive gain that a mosquito can have as a result of successfully acquiring a blood meal from the human consequent from a successful interaction. The new framework that we employ uses a continuous time mathematical modelling approach. We have been able to show how this alternate framework for malaria modelling captures the existence of periodic oscillations, backward bifurcation and even period doubling bifurcation leading to chaos in the dynamics of malaria transmission; phenomena that are rarely observed in unforced continuous time models for malaria transmission. Our work clearly shows how to use mathematical modelling to target vulnerable spots on the malaria transmission chain.