Influence of Magnetic Fields on Magneto-Aerotaxis

Abstract

The response of cells to changes in their physico-chemical micro-environment is essential to their survival. For example, bacterial magnetotaxis uses the Earth's magnetic field together with chemical sensing to help microorganisms move towards favoured habitats. The studies of such complex responses are lacking a method that permits the simultaneous mapping of the chemical environment and the response of the organisms, and the ability to generate a controlled physiological magnetic field. We have thus developed a multi-modal microscopy platform that fulfils these requirements. Using simultaneous fluorescence and high-speed imaging in conjunction with diffusion and aerotactic models, we characterized the magneto-aerotaxis of Magnetospirillum gryphiswaldense. We assessed the influence of the magnetic field (orientation; strength) on the formation and the dynamic of a micro-aerotactic band (size, dynamic, position). As previously described by models of magnetotaxis, the application of a magnetic field pointing towards the anoxic zone of an oxygen gradient results in an enhanced aerotaxis even down to Earth's magnetic field strength. We found that neither a ten-fold increase of the field strength nor a tilt of 45u resulted in a significant change of the aerotactic efficiency. However, when the field strength is zeroed or when the field angle is tilted to 90u, the magneto-aerotaxis efficiency is drastically reduced. The classical model of magneto-aerotaxis assumes a response proportional to the cosine of the angle difference between the directions of the oxygen gradient and that of the magnetic field. Our experimental evidence however shows that this behaviour is more complex than assumed in this model, thus opening up new avenues for research.

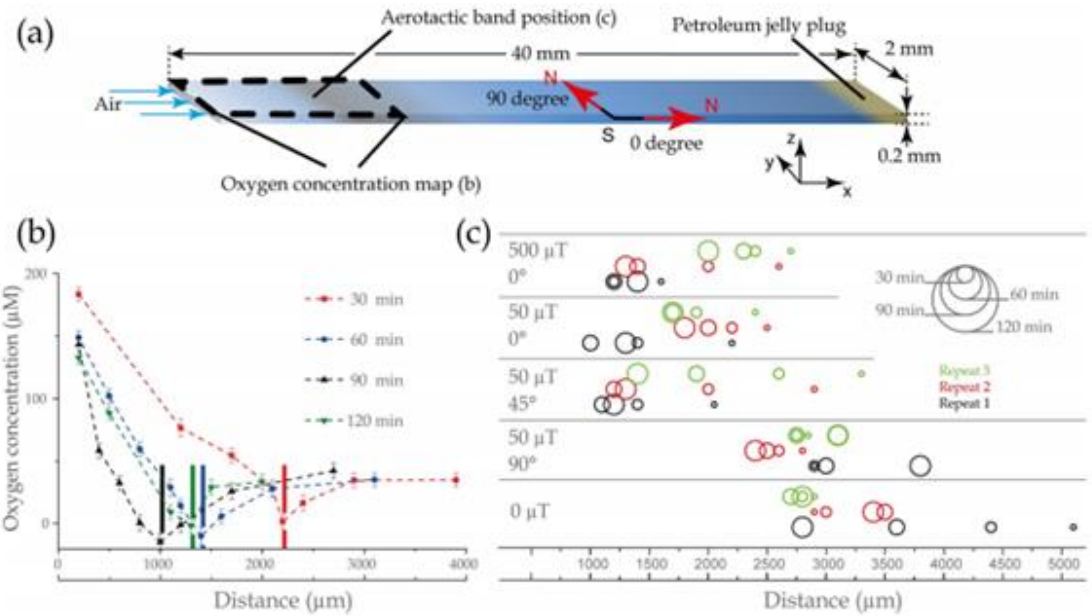

Figure 1. Microcapillary assay and magnetotaxis, experimental results: (a) Schematic of the capillary showing the generation of an oxygen gradient due to air diffusion at one end of the capillary, the consumption by the bacteria at the aerotactic band position shown in (c), and the jelly plug at the other end of the capillary; the area corresponding to the oxygen gradient measured and shown in (b); a schematic of the magnetic field conditions corresponding to 50 µT, at 0° and 90° to the length of the capillary; and the orientation of the x-, y- and z-axis according to how they are referred to in the text. (b) Graph showing the evolution of the oxygen gradient generated and the position of the bacteria in the capillary following the sample preparation (See Figure S7 for other conditions). The measurements are performed after 30 min (red square); 60 min (blue circles); 90 min (black triangles); and 120 min (inversed green triangle). The aerotactic band position is marked by a bar the colour of which corresponds to the colours used to plot the gradients. (c) Position of the aerotactic band when the Earth's magnetic field is cancelled (black squares), a magnetic field of 50 µT is applied and the North pole points towards the anaerobic region (red circles), a magnetic field of 500 µT is applied and the North pole points towards the anaerobic region (blue triangles), a magnetic field of 50 µT is applied and the North pole points at 45° to the capillary long axis towards the anaerobic region (green reverse triangles), a magnetic field of 50 µT is applied and the North pole points at 90° to the capillary long axis (brown squares). Each point represents the position of the aerotactic band at a given time after the beginning of an experiment averaged over three distinct experiments.