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Mechanical Coordination of Single-Cell and Collective-Cell Amoeboid Migration

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Amoeboid migration consists of the sequential repetition of pseudopod extensions and retractions driven by actin polymerization and actomyosin contraction, and requires cells to apply mechanical forces on their surroundings. We measure the three-dimensional forces exerted by chemotaxing Dictyostelium cells, and examine wild-type cells as well as mutants with defects in contractility, F-actin polymerization, internal F-actin crosslinking, and cortical integrity. We find that cells pull on their substrate adhesions using two distinct, yet interconnected mechanisms: axial actomyosin contractility and cortical tension. The 3D pulling forces generated by both mechanisms are internally balanced by an increase in cytoplasmic pressure that allows cells to push on their substrate, and we show that these pushing forces are relevant for cell invasion and migration in three-dimensional environments. We observe that cells migrate mainly by forming two stationary adhesion sites at the front and back of the cell, over which the cell body moves forward in a step-wise fashion. During this process, the traction forces at each adhesion site are switched off and subsequently their direction is reversed. The cell migration speed is found to be proportional to the rate at which cells are able regulate these forces to produce the cell shape changes needed for locomotion, which is increased when axial contractility overcomes the stabilizing effect of cortical tension. This spatiotemporal coordination is conserved in streams of multiple migratory cells connected head to tail, which also migrate by exerting traction forces on stationary sites. Furthermore, we observe that trailing cells reuse the adhesion sites of the leading cells. Finally, we provide evidence that the above modes of migration may be conserved in a range of other amoeboid-type moving cells such as neutrophils.