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Review

Myosin I: From yeast to human

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Abstract. Myosin I is a non-filamentous, single-headed, actin-binding motor protein and is present in a wide range of species from yeast to man. The role of these class I myosins have been studied extensively in simple eukaryotes, showing their role in diverse processes such as actin cytoskeleton organization, cell motility, and endocytosis. Recently, studies in metazoans have begun to reveal more specialized functions of myosin I. It will be a major challenge in the future to examine the physiological functions of each class I myosin in different cell types of metazoans.

Keywords. Myosin I, actin, vertebrate.

Introduction

Myosins are a family of proteins with actin-based motor activity that play diverse roles in biological processes [1, 2]. Recent studies have shown that there are 37 distinct types of myosins in eukaryotes [3, 4]. Class I myosins are non-filamentous and have N-terminal motor domain, several IQ motifs that bind to regulatory light chains such as calmodulin, and a TH1 domain that is rich in basic residues [5, 6]. They can be subdivided into short forms and long forms of class I myosin. The long forms have additional proline-rich TH2 and Src homology 3 (SH3) domains [5, 6]. Class I myosin is proposed to be present in the last common ancestor of eukaryotes, making it as one of the earliest myosin proteins [3]. After the original discovery of myosin I in *Acanthamoeba* [7], extensive studies of class I myosins have been performed in single-celled eukaryotes of "low complexity" such as yeast [8, 9] and *Dictyostelium* [10–12]. These studies have shown the roles of myosin I in actin polymerization, cell motility and vesicular transport. Recently, studies in metazoans have demonstrated interesting new biological functions of class I myosins. We summarize those findings and discuss their implications for the general function of class I myosins.

Yeast myosin I: Association with actin polymerization complex

Saccharomyces cerevisiae and *Schizosaccharomyces pombe* have been extensively utilized for the study of the role of myosin I in yeast [8, 9, 13]. While *S. cerevisiae* has two class I myosins, Myo3p and Myo5p, *S. pombe* has only Myo1p [14], suggesting that even these simplest, non-motile eukaryotes have diversified myosin I to adapt to their different life styles [9]. Class I myosins in yeast are all long-tailed. They also have unique acidic domains in the C terminus [15, 16] unlike the long-tailed myosins in other species. Deletion of *MYO3* alone in *S. cerevisiae* did not lead

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to any obvious phenotype [17], although the *MYO5* mutation caused a significant decrease in the rate of endocytosis [18]. Deletion mutants of both genes exhibited depolarized actin patches, defects in growth, and fluid-phase endocytosis, suggesting that Myo3p and Myo5p have overlapping functions [15, 18]. Deletion of *myo1* in *S. pombe* also showed a defect in actin cytoskeleton distribution [19, 20]. Myo3p and Myo5p interact with both Bee1p/Las17p and Vrp1p, which are the homologs of human WASP (Wiskott-Aldrich Syndrome protein) and WIP (WASP-interacting protein), respectively. These interactions are mediated by SH3 domain of Myo3p and Myo5p. They also interact with the Arp2/3 actin nucleation complex through the C-terminal acidic domain [19, 21–24]. Therefore, yeast myosin I probably mobilizes the actin polymerization complex to the cell cortex and participates in its regulation [19, 21–25]. Although myosin I in other species lacks the acidic domain that interacts with the Arp2/3 complex, another protein, CARMIL, was shown to mediate interaction between myosin I and Arp2/3 complex in *Dictyostelium* [26]. The motor activity of myosin I is required for actin polymerization in yeast [23] and is controlled by phosphorylation of the motor domain [6, 27]. Control of motor activity of *Dictyostelium* myosin I is also accomplished by phosphorylation of serine or threonine residues within the catalytic head domain [6]. However, the conserved phosphorylation sites of lower eukaryotes are absent in vertebrate class I myosins and their ATPase activity is controlled by Ca^{2+}/calmodulin or auto-inhibition by C-terminal SH3 domain [6].

Dictyostelium myosin I: Not essential, but still required for proper responses

Dictyostelium has been a good model to study the mechanisms of cell motility since it is a single-celled eukaryote but, nevertheless, still has many similarities in chemotactic responses to metazoan cells of higher eukaryotes [28]. Upon exposure to a chemoattractant gradient, *Dictyostelium* and neutrophils of the immune system of higher eukaryotes extend an actin-dependent structure, called a pseudopod at the anterior end of the cell. Later, it is followed by waves of posterior contraction and retraction [29], resulting in cell migration. *Dictyostelium* has three long-tailed myosin I isoforms (MyoB, MyoC, MyoD), three short-tailed myosin I isoforms (MyoA, MyoE, MyoF) and another myosin I (MyoK) with no tail [11]. Initial studies using fluorescence microscopy of migrating *Dictyostelium* showed that MyoB was concentrated in lamellipodial projections [30], suggesting that myosin I might contribute to the generation of the forces for leading edge extension. When the *myoB* gene was disrupted using homologous recombination, *Dictyostelium* exhibited delayed migration [31]. This mutant formed lateral pseudopods three times more frequently and, so, turned more often, leading to a decrease in the net migration rate [32]. These results suggest that MyoB in *Dictyostelium* is not required for pseudopod formation itself, but rather crucial for suppressing unnecessary lateral pseudopods to keep the persistence of cell translocation. Unlike *myoB*, mutants of other long-tailed myosin I (*myoC*, *myoD*) did not exhibit any significant defect in migration [33]. It is possible that these long-tailed class I myosins contribute to motility in proportion to their expression level since the amount of MyoB is much higher than MyoC and MyoD during the streaming stage [33]. In addition to MyoB, other forms of myosin I (MyoA, MyoF, MyoK) are required for proper cell motility of *Dictyostelium*. MyoA- or MyoF-deficient *Dictyostelium* recapitulated the phenotype of *myoB* null mutants, showing an increase in lateral pseudopod formation and a decrease in overall velocity of migration [34, 35]. Furthermore, *myoK* null mutants showed slower translocation and excessive lamellipodia formation [36].

Macropinocytosis (fluid-phase pinocytosis) in *Dictyostelium* is another actin-dependent process in which myosin I play a role. Whereas single myosin I null mutants did not exhibit any defect in macropinocytosis, double null mutants of long-tailed myosins (*myoB-*/*myoC-*, *myoB-*/*myoD-*) or null mutants of both long- and short-tailed myosins (*myoA-*/*myoB-*) showed significant reduction in the rate of macropinocytosis [33, 37]. These results suggest that more than one myosin I work together cooperatively regardless of the tail length. This defect did not seem to be the result of abnormality in the endosomal pathway since various properties such as intravesicular pH, intracellular retention time, and exocytosis of a fluid-phase marker were normal [38]. A reduced number of large endocytic vesicles in the mutants indicated that a defect existed at an early stage of internalization [37]. Interestingly, double null mutants (*myoA-*/*myoB-*, *myoB-*/*myoC-*) extended more actin-rich crowns on the surface, which was reminiscent of the phenotype during cell translocation [37]. This abnormal cytoskeletal rearrangement near the plasma membrane may have caused a delay in the internalization of fluid-filled projections [37].

Taken together, the reduced velocity of cell migration and the decreased rate of macropinocytosis in multiple myosin I mutants suggest that there is no single myosin I that is essential for these fundamental actin-dependent processes and that each myosin I contributes to making these processes more efficient. One

possible underlying mechanism for these phenotypes is that myosin I contributes to the generation of resting cortical tension, *i.e.*, the force that maintains the round shape of the cells [39]. It has been proposed that this tension may affect cell motility and endocytosis [40]. While overexpression of myosin I increased the cortical tension dramatically [41], single null mutants of *myoA*, *myoB*, *myoC* did not show a significant decrease compared to the wild type, with the exception of myoK mutants [36, 41]. However, double or triple null mutants of myosin I exhibited a severe reduction in cortical tension, suggesting that class I myosins synergize in this process [41]. Since *myoA*, *myoB* single null mutants showed abnormally frequent pseudopods [32, 34], this phenotype does not seem to be directly related to the changes in cortical tension [10]. How myosin I suppresses lateral pseudopod formation therefore still remains elusive. Meanwhile, it is plausible that there is a threshold for changes in cortical tension, which can affect macropinocytosis [10]. At this moment, it is not clear how myosin I plays a role in the generation of cortical tension. First, it is possible that class I myosins apply contractile force or cross-link the actin network near the plasma membrane [36, 41]. Alternatively, it is also possible that myosin I is directly involved in cortical actin dynamics proximal to the plasma membrane, since *Dictyostelium* myosin I can interact with the Arp2/3 actin nucleation complex through CARMIL [26]. CARMIL mutants exhibited a decreased rate of fluid-phase endocytosis and chemotaxis, suggesting that at least part of myosin I function is linked to CARMIL [26]. CARMIL homologs exist in *Caenorhabditis elegans*, *Drosophila*, mouse, and human [26, 42], but their interaction with myosin I in those organisms has not been confirmed.

Consistent with the cortical function described above, myosin I plays another nonessential, but supporting role in actin-dependent phagocytosis. It was shown that MyoB and MyoD were localized to the phagocytic cups [30, 43] and single null mutants of *myoB*, *myoC* and *myoK* exhibited a significant reduction in the rate of phagocytosis [31, 33, 36], although another study showed that *myoC* mutants did not have a defect in phagocytosis [44].

Drosophila myosin I: Crucial to the formation of left/right asymmetry

The *Drosophila* genome encodes two class I myosins, Myo31DF (*Drosophila* myosin IA) and Myo61F (Drosophila myosin IB) [14], which are the orthologs of Myo1d and Myo1c in vertebrates, respectively [45, 46]. Recently, screening of genes determining left/right asymmetry led to the identification of Myo31DF [47, 48]. Loss of Myo31DF function caused reversal of left/right asymmetry in visceral organs and this function seemed to be dependent on the actin cytoskeleton [47, 48]. Yeast two hybrid screening identified Armadillo, a *Drosophila* homolog of β-catenin, as a binding partner for Myo31DF [47]. It has been proposed that Myo31DF transports specific vesicles along the actin cytoskeleton to induce asymmetry [47]. Meanwhile, overexpression of the other myosin I, Myo61F also caused inversion of left/right axis [48]. Therefore, it was hypothesized that Myo31DF and Myo61F antagonized each other during axis formation [48]. These studies suggested a crucial role of the actin cytoskeleton in left/right axis formation in invertebrates. However, vertebrates use microtubules in nodal cilia as a cytoskeletal basis for asymmetry [49]. Therefore, it is unlikely that this function of class I myosin in *Drosophila* is conserved in vertebrates [49]. Instead, inversion seems to play an equivalent role in vertebrates by interacting with β-catenin [49].

Vertebrate myosin I

There has been confusion in the vertebrate myosin I nomenclature and new nomenclature has been proposed [50]. Humans and mice have a total of eight class I myosin genes, six of which encode short-tailed forms (Myo1a, b, c, d, g, and h) and two of which encode long-tailed forms (Myo1e, f) [14]. These vertebrate forms of class I myosin exhibit more diversity in their function compared to *Dictyostelium* class I myosins. There are several reviews about vertebrate myosin I [5, 6, 51–54], which cover literature not described in this review.

Myo1A (Brush-border myosin I)

Myo1A is the first class I myosin identified in vertebrate cells [55–57]. It binds three to four calmodulin molecules and as a result Ca^{2+} can regulate its enzymatic activity with different outcomes, depending on the number of calmodulins associated [58, 59]. While multiple mutations of Myo1A have been reported among patients with nonsyndromic hearing loss [60], *Myo1A* mRNA expression is actually enriched in the small intestine and to a lesser extent in colon in humans [61]. Myo1A is particularly abundant in the apical surface of the intestine (brush-border domain) where microvilli contain actin bundles extending into the tip [61]. It has been shown that chicken Myo1a can interact with phospholipid through its tail domain [62], suggesting its role in tethering the actin bundles of microvilli to

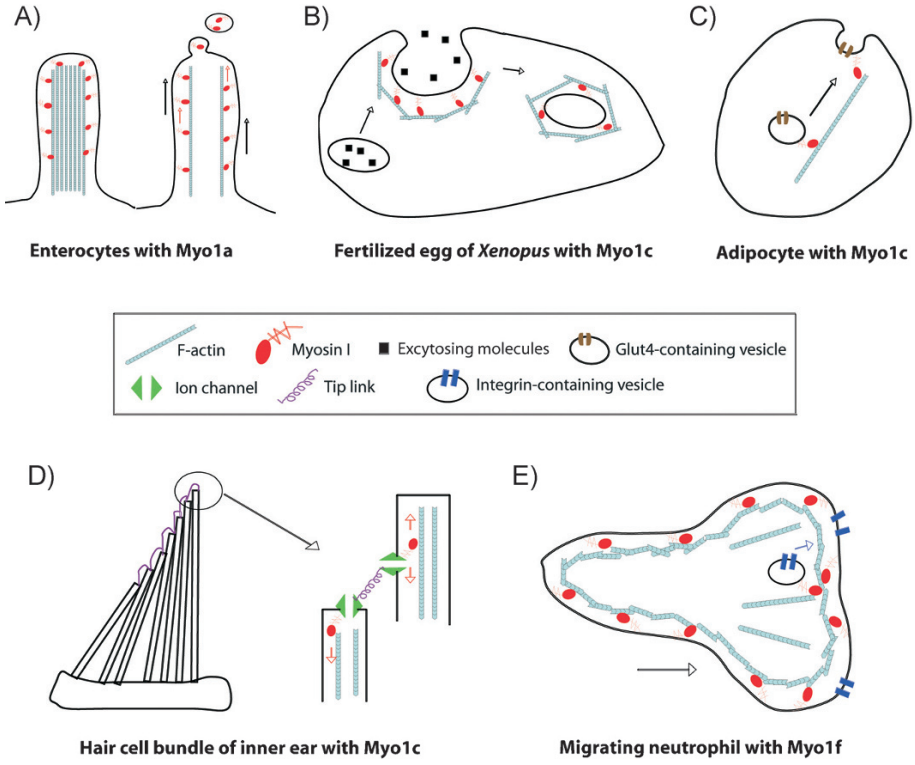

Figure 1. Function of vertebrate myosin I. (*A*) Myo1a connects the actin cytoskeleton to plasma membrane of microvilli in enterocytes or brings the membrane toward villus tip along the actin bundles. (*B*) Fertilization of *Xenopus* egg induces cortical granule exocytosis. Myo1c couples actin polymerization to exocytosing granules, promoting subsequent compensatory endocytosis. (*C*) Myo1c in adipocytes transports GLUT4-containing vesicles to plasma membrane upon insulin stimulation. (*D*) Myo1c in hair cells of the inner ear regulates the opening of ion channel by controlling tension transmitted to ion channel through tip link during deflection of hair bundle. (*E*) Myo1f in neutrophils prevents excessive exocytosis of integrin-containing vesicles by regulating cortical F-actin or by controlling the final step of exocytosis. This process ensures proper adhesion and efficient cell motility.

the plasma membrane. There seems to be an additional requirement for membrane binding of this tail domain and motor activity [63, 64]. Myo1a-null mice did not exhibited any phenotype at the whole animal level, but showed varying levels of perturbation in brush-border structures, including villus shortening, poor packing of microvilli, herniation of apical membrane, and loss of numerous components from the brush border [65]. Ectopic recruitment of Myo1c to brush borders in Myo1a-null mice was also observed and might be responsible for partial functional compensation and thus, for the lack of phenotype at the whole animal level [65]. Based on these findings, it has been proposed that Myo1a contributes to membrane tension in microvilli by connecting cytoskeleton to the membrane [65]. Meanwhile, the presence of Myo1a at the cytoplasmic side of Golgi-derived vesicles has suggested that it may perform another function in vesicle transport, specifically, taking over the final step of movement along the actin cortex from dynein on microtubule [66, 67]. Recently, it has been shown that Myo1a brings the apical membrane toward the microvillus tip along the actin bundles (Fig. 1A), leading to the shedding of the membrane as vesicles [68]. Although the physiological function of this process in the small intestine is not clear at present, this observation clearly demonstrates a role of Myo1a as a motor and implies that the phenotypes of Myo1a-deficient mouse might be due in part to abnormal membrane trafficking [68].

Myo1B (myosin-Iα, Myr 1)

Rat Myo1B (Myr 1) shares 47 % homology in the tail domain with Myo1A and exists in three alternative spliced forms, differing in the number (four to six) of calmodulin binding motifs [69, 70]. High concentration of Ca^{2+} induced one or more calmodulin dissociation and decreased its motor activity [71]. Myo1b differs from Myo1a by having widespread expression including lung, liver, heart, and brain [69, 70]. In addition, Myo1b is not localized at static, but rather at dynamic actin structures, such as membrane ruffles [72, 73]. It has been also shown that a truncated form of Myo1b impairs the distribution of lysosomes and their long-range movement, suggesting its role in the transport of the vesicles [74].

Myo1C (myosin Iβ, Myr 2)

Myo1c is another class I myosin identified from various sources [70, 75–78]. It has three calmodulin (light chain)-binding sites and is bound by two to three calmodulins in the absence of Ca^{2+} [79]. Elevated Ca^{2+}concentration induces release of calmodulin and increase of ATPase activity of Myo1c [75, 79]. In addition, Ca^{2+} binding to calmodulin can inhibit its motor activity [80]. It has a wide range of expression in tissues, with enrichment in actin-rich structure near

the plasma membrane [70, 81, 82] and in phagocytic cups [83]. Interestingly, its expression was observed in sensory hair cells of the inner ears, particularly at stereociliary tips of the hair bundle [84, 85]. This observation led to the hypothesis that Myo1c may work as adaptation motors, regulating tip link associated ion channels, thus controlling sensitivity [86] (Fig. 1D). To test this hypothesis, myo1c mutants in which ATPase activity is inhibited in the presence of ADP analogs [87] were overexpressed in transgenic mice. Delivery of an ADP analog selectively reduced the adaptation in mutant expressing hair cells, indicating that Myo1c indeed works as an adaptation motor [88]. Myo1c seems to be localized at the tip link through binding to phosphatidylinositol 4,5-bisphosphate (PIP_2) and cadherin 23 [89–92].

Myo1c is also involved in glucose transporter 4 (GLUT4)-containing vesicle movement [93]. GLUT4 is sequestered intracellularly in the absence of insulin and insulin induces redistribution of GLUT4 to the plasma membrane, which is important for glucose uptake. Myo1c was found to be associated with GLUT4-containing vesicles upon insulin stimulation (Fig. 1C) and GLUT4 transport to the plasma membrane was enhanced by overexpression of Myo1c [93]. In addition, expression of the tail domain of Myo1c or the cognate RNAi inhibited this process, suggesting that Myo1c might transport vesicles to plasma membrane along actin filaments [93]. Further studies are required to clarify the mechanism of action of Myo1c in GLUT4-containing vesicle movement. However, studies of Myo1c in *Xenopus* egg have suggested a different possibility. *Xenopus* Myo1c expression is increased during meiotic maturation. Egg fertilization in vertebrates and invertebrates triggers a sequence of events, including cortical granule exocytosis that is required for blocking polyspermy and assembly of actin coats around exocytosing granules, which is required for compensatory endocytosis (Fig. 1B). When headless Myo1c was expressed in *Xenopus* oocytes to inhibit the function of Myo1c, fertilization still induced actin assembly but actin coats were misdirected and uncoupled from exocytosing granules, resulting in delayed exocytosis, failure of compensatory endocytosis and increased actin assembly in cortical regions. These results imply that Myo1c links polymerizing actin to a particular membrane compartment instead of acting as a transporter [94]. In relation to this result, it is interesting to observe that Myo1c binds to PIP_2 through a putative a pleckstrin homology domain [91]. Myo1c was also observed in the nucleus [95]. This nuclear Myo1c differs from cytoplasmic Myo1c by having additional 16 amino acids at the N terminus, which constitute an NLR and direct its location in the nucleus [96]. Translation from another start site upstream of exon 1 of cytoplasmic Myo1c, generates nuclear Myo1c [96]. Nuclear Myo1c interacts with both RNA polymerase I and RNA polymerase II. Furthermore, antibody against Myo1c inhibits transcription in cultured cells and *in vitro*, suggesting that nuclear Myo1c is involved in transcription [96, 97]. It is not yet clear at which step of transcription nuclear Myo1c acts [98, 99]. In addition, nuclear compartmentalization has been observed to depend on the transcription status of the locus, and redistribution of Myo1c to transcriptionally active region of nucleus was observed upon stimulation [100]. Nuclear Myo1c mutants show delayed repositioning of transcriptionally active locus by several hours, suggesting that nuclear Myo1c is involved in a directed long-range chromosome movement apart from its function in transcription [101]. The exact mechanism underlying this phenomenon is not yet known [101].

Myo1D (myosin Iγ, Myr 4)

Myo1d was initially found in mouse brain tissues and rat liver [70, 102]. Further analysis of rat Myo1d (Myr 4) has demonstrated that it is widely expressed in various tissues, with the highest expression in brain [103]. Myo1d has two calmodulin (light chain) binding sites in the neck region and an additional site in the tail domain, with different Ca^{2+} dependence on binding [103]. Binding of Ca^{2+} to calmodulin can inhibit ATPase activity of Myo1d [104]. Fusion of early endosomes with recycling endosomes *in vitro* was specifically inhibited by an antibody against the tail region of rat Myo1d, suggesting that Myo1d is involved in the membrane recycling pathway [105].

Myo1E (myosin-IC, Myr 3) and Myo1F (myosin-ID, chicken myosin IB)

Human Myo1E [106], its rat ortholog Myr-3 [107], and another related long-tailed myosin member (Myo1f) [108–110] have been identified. Although initial studies indicated their widespread expression in various tissues [106, 107, 110], complete knowledge of their sequences allowed us to detect differential expression of these isoforms in mouse tissues [111]. Both mouse Myo1e and Myo1f are highly expressed in immune cells, but some immune cells exhibited exclusive expression of a particular long-tailed myosin I, such as Myo1e in B cells and Myo1f in neutrophils [111].

Since Myo1f is the only long-tailed myosin I in neutrophils and since neutrophils and *Dictyostelium* have many similarities in their cellular responses to chemoattractants [28], it was hypothesized that Myo1f-deficient neutrophils would have abnormal migration. Indeed, Myo1f-deficient mice showed

deficient neutrophil mobilization and were susceptible to infection by *Listeria monocytogenes* [111]. However, time-lapse microscopy of migrating neutrophils *in vitro* demonstrated that, unlike the frequently turning *Dictyostelium myoB* null mutants [32], Myo1f-deficient neutrophils responded to chemoattractant normally on poly-lysine-coated surface [111]. Instead, migration of Myo1f-deficient neutrophils was impaired specifically on integrin-ligand-coated surfaces [111], which resemble the physiological environment. β2 integrin is important for adhesion and motility of neutrophils in the extracellular environment. A large pool of β2 integrin is stored in cytoplasmic granules of neutrophils, allowing rapid regulation of the surface level of β2 integrin [112]. In the absence of Myo1f, neutrophils exhibited excessive adherence to integrin ligand as a result of augmented exocytosis of β2 integrin-containing granules [111]. Similar oversecretion of lysosomal granules was observed in *Dictyostelium* mutants [38], although it did not seem to result in a migration defect. In addition, absence of Myo1f reduced the amount of cortical F-actin near the plasma membrane, with which Myo1f colocalized [111]. It has been proposed that cortical F-actin works as a barrier against secretory granule exocytosis [113] (Fig. 1E). Therefore, one hypothesis is that Myo1f regulates local actin network dynamics near the plasma membrane and that the absence of Myo1f causes this network to become loose, allowing more large granules to be secreted [114]. Another possibility is that Myo1f may play a negative role in granule translocation near the plasma membrane [111].

Taken together, Myo1f of neutrophils is similar to MyoB of *Dictyostelium,* in that it is not required for chemotaxis *per se* to occur, but to increase the efficiency of the response [32, 111]. However, the mechanisms underlying this role are quite different. While myoB of *Dictyostelium* maintains the persistency of migration by preventing lateral pseudopod formation [32], Myo1f of neutrophils modulates adhesion to the extracellular environment by preventing excessive granule exocytosis [111]. Despite these differences in the mechanisms of their contribution to motility, it is still possible that there is commonality in the molecular function of these class I myosins between the two different genera. We should, however, keep in mind that there are several differences in the cell biology of the cortical region between protozoans and metazoans. First, unlike in protozoans, integrin plays an important role in the interaction of metazoan cells with extracellular environment. This probably has affected the evolution of vertebrate cells and their cytoskeletal components such as Myo1 f. Second, it has been observed that there is a large difference in the resting cortical tension between neutrophils (0.035 dyn/cm) [115, 116] and *Dictyostelium* (1.5 dyn/cm) [10, 41]. It would, therefore, be better to consider these differences first when extending hypotheses from protozoan studies to vertebrate and vice versa.

With respect to the function of Myo1f in the immune system, it is interesting to note that the *Myo1F* gene is fused to the mixed lineage leukemia (MLL) gene in acute monocytic leukemia [117]. It is not yet known whether MLL-Myo1F fusion proteins play a role in leukemogenesis and whether gain or loss of function of Myo1F is involved in this process. Also, Myo1F has been proposed to be a candidate gene for nonsyndromic deafness [118]. Further analysis of Myo1f-deficient mice will be helpful to clarify these questions.

Myo1e associates with one calmodulin molecule as a light chain, independent of Ca^{2+} [119]. The ATPase activity of Myo1e is inhibited by Ca^{2+} binding or by its own C-terminal SH3 domain [119]. Rat Myo1e (Myr 3) was originally found to be localized in the F-actin-rich region at the cell-cell contact, suggesting its relationship with membrane-associated actin structure [107, 120]. In addition, localization of Myo1e around the phagosome in the macrophage implied a role in phagosome closure [121, 122]. Recently, it has been shown that human Myo1E interacts with synaptojanin-1 and dynamin, [123] and expression of the tail domain of Myo1E inhibited transferrin endocytosis, suggesting its role in clathrin-mediated endocytosis [123]. Expression of Myo1e was also reported in the hair cells of the auditory and vestibular epithelia, particularly in the cuticular plates with actin meshwork [124]. It would be interesting to examine defects in these functions in the absence of Myo1e.

Concluding remarks

Class I myosin exists in a variety of species from yeast to man. However, unlike protozoa, metazoan cells have evolved to differentiate into distinct types with specialized function. Therefore, the expression pattern of each class I myosin varies between these cells [111] and, in addition, myosin I has also evolved to perform different functions depending on the environment [54, 94, 98]. It will be a future challenge to determine the physiological function of class I myosins in different types of metazoan cells. Their cell type-specific functions and underlying molecular mechanisms may shed further light onto how each system has evolved to adopt the actin cytoskeleton for their own specialized cellular functions.

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1 Sellers, J. R. (2000) Myosins: A diverse superfamily. Biochim. Biophys. Acta 1496, 3–22.
2 Krendel, M. and Mooseker, M. S. (2005) Myosins: Tails (and heads) of functional diversity. Physiology (Bethesda) 20, 239–251.
3 Richards, T. A. and Cavalier-Smith, T. (2005) Myosin domain evolution and the primary divergence of eukaryotes. Nature 436, 1113–1118.
4 Foth, B. J., Goedecke, M. C. and Soldati, D. (2006) From the Cover: New insights into myosin evolution and classification. Proc. Natl. Acad. Sci. USA 103, 3681–3686.
5 Coluccio, L. M. (1997) Myosin I. Am. J. Physiol. Cell Physiol. 273, C347–359.
6 Barylko, B., Binns, D. D. and Albanesi, J. P. (2000) Regulation of the enzymatic and motor activities of myosin I. Biochim. Biophys. Acta 1496, 23–35.
7 Pollard, T. D. and Korn, E. D. (1973) *Acanthamoeba* myosin. I. Isolation from *Acanthamoeba castellanii* of an enzyme similar to muscle myosin. J. Biol. Chem. 248, 4682–4690.
8 Brown, S. S. (1997) Myosins in yeast. Curr. Opin. Cell Biol. 9, 44–48.
9 Win, T. Z., Mulvihill, D. P. and Hyams, J. S. (2002) Take five: A myosin class act in fission yeast. Cell Motil. Cytoskeleton 51, 53–56.
10 Titus, M. A. (2000) The role of unconventional myosins in *Dictyostelium* endocytosis. J. Eukaryot. Microbiol. 47, 191–196.
11 de la Roche, M. A. and Cote, G. P. (2001) Regulation of *Dictyostelium* Myosin I and II. Biochim. Biophys. Acta 1525, 245–261.
12 Soldati, T. (2003) Unconventional myosins, actin dynamics and endocytosis: A menage a trois? Traffic 4, 358–366.
13 Tanaka, K. and Matsui, Y. (2001) Functions of unconventional myosins in the yeast *Saccharomyces cerevisiae.* Cell Struct. Funct. 26, 671–675.
14 Berg, J. S., Powell, B. C. and Cheney, R. E. (2001) A millennial myosin census. Mol. Biol. Cell 12, 780–794.
15 Goodson, H. V., Anderson, B. L., Warrick, H. M., Pon, L. A. and Spudich, J. A. (1996) Synthetic lethality screen identifies a novel yeast myosin I gene (MYO5): Myosin I proteins are required for polarization of the actin cytoskeleton. J. Cell Biol. 133, 1277–1291.
16 Machesky, L. M. (2000) The tails of two myosins. J. Cell Biol. 148, 219–221.
17 Goodson, H. V. and Spudich, J. A. (1995) Identification and molecular characterization of a yeast myosin I. Cell Motil. Cytoskeleton 30, 73–84.
18 Geli, M. I. and Riezman, H. (1996) Role of type I myosins in receptor-mediated endocytosis in yeast. Science 272, 533–535.
19 Lee, W. L., Bezanilla, M. and Pollard, T. D. (2000) Fission yeast myosin-I, Myo1p, stimulates actin assembly by Arp2/3 complex and shares functions with WASp. J. Cell Biol. 151, 789–800.
20 Toya, M., Motegi, F., Nakano, K., Mabuchi, I. and Yamamoto, M. (2001) Identification and functional analysis of the gene for type I myosin in fission yeast. Genes Cells 6, 187–199.
21 Anderson, B. L., Boldogh, I., Evangelista, M., Boone, C., Greene, L. A. and Pon, L. A. (1998) The Src homology domain 3 (SH3) of a yeast type I myosin, Myo5p, binds to verprolin and is required for targeting to sites of actin polarization. J. Cell Biol. 141, 1357–1370.
22 Evangelista, M., Klebl, B. M., Tong, A. H., Webb, B. A., Leeuw, T., Leberer, E., Whiteway, M., Thomas, D. Y. and Boone, C. (2000) A role for myosin-I in actin assembly through interactions with Vrp1p, Bee1p, and the Arp2/3 complex. J. Cell Biol. 148, 353–362.
23 Lechler, T., Shevchenko, A. and Li, R. (2000) Direct involvement of yeast type I myosins in Cdc42-dependent actin polymerization. J. Cell Biol. 148, 363–373.
24 Geli, M. I., Lombardi, R., Schmelzl, B. and Riezman, H. (2000) An intact SH3 domain is required for myosin I-induced actin polymerization. EMBO J. 19, 4281–4291.
25 Soulard, A., Lechler, T., Spiridonov, V., Shevchenko, A., Li, R. and Winsor, B. (2002) *Saccharomyces cerevisiae* Bzz1p is implicated with type I myosins in actin patch polarization and is able to recruit actin-polymerizing machinery *in vitro.* Mol. Cell. Biol. 22, 7889–7906.
26 Jung, G., Remmert, K., Wu, X., Volosky, J. M. and Iii, J. A. H. (2001) The *Dictyostelium* CARMIL protein links capping protein and the Arp2/3 complex to type I myosins through their SH3 domains. J. Cell Biol. 153, 1479–1498.
27 Wu, C., Lytvyn, V., Thomas, D. Y. and Leberer, E. (1997) The phosphorylation site for Ste20p-like protein kinases is essential for the function of myosin-I in yeast. J. Biol. Chem. 272, 30623–30626.
28 Parent, C. A. (2004) Making all the right moves: Chemotaxis in neutrophils and *Dictyostelium.* Curr. Opin. Cell Biol. 16, 4–13.
29 Devreotes, P. N. and Zigmond, S. H. (1988) Chemotaxis in eukaryotic cells: A focus on leukocytes and *Dictyostelium.* Annu. Rev. Cell Biol. 4, 649–686.
30 Fukui, Y., Lynch, T. J., Brzeska, H. and Korn, E. D. (1989) Myosin I is located at the leading edges of locomoting *Dictyostelium* amoebae. Nature 341, 328–331.
31 Jung, G. and Hammer, J. A. 3rd. (1990) Generation and characterization of *Dictyostelium* cells deficient in a myosin I heavy chain isoform. J. Cell Biol. 110, 1955–1964.
32 Wessels, D., Murray, J., Jung, G., Hammer, J. A. 3rd. and Soll, D. R. (1991) Myosin IB null mutants of *Dictyostelium* exhibit abnormalities in motility. Cell Motil. Cytoskeleton 20, 301–315.
33 Jung, G., Wu, X. and Hammer, J. A. 3rd. (1996) *Dictyostelium* mutants lacking multiple classic myosin I isoforms reveal combinations of shared and distinct functions. J. Cell Biol. 133, 305–323.
34 Titus, M. A., Wessels, D., Spudich, J. A. and Soll, D. (1993) The unconventional myosin encoded by the myoA gene plays a role in *Dictyostelium* motility. Mol. Biol. Cell 4, 233–246.
35 Falk, D. L., Wessels, D., Jenkins, L., Pham, T., Kuhl, S., Titus, M. A. and Soll, D. R. (2003) Shared, unique and redundant functions of three members of the class I myosins (MyoA, MyoB and MyoF) in motility and chemotaxis in *Dictyostelium.* J. Cell Sci. 116, 3985–3999.
36 Schwarz, E. C., Neuhaus, E. M., Kistler, C., Henkel, A. W. and Soldati, T. (2000) *Dictyostelium* myosin IK is involved in the maintenance of cortical tension and affects motility and phagocytosis. J. Cell Sci. 113, 621–633.
37 Novak, K. D., Peterson, M. D., Reedy, M. C. and Titus, M. A. (1995) *Dictyostelium* myosin I double mutants exhibit conditional defects in pinocytosis. J. Cell Biol. 131, 1205–1221.
38 Temesvari, L. A., Bush, J. M., Peterson, M. D., Novak, K. D., Titus, M. A. and Cardelli, J. A. (1996) Examination of the endosomal and lysosomal pathways in *Dictyostelium discoideum* myosin I mutants. J. Cell Sci. 109, 663–673.
39 Yeung, A. and Evans, E. (1989) Cortical shell-liquid core model for passive flow of liquid-like spherical cells into micropipets. Biophys. J. 56, 139–149.
40 Sheetz, M. P. and Dai, J. (1996) Modulation of membrane dynamics and cell motility by membrane tension. Trends Cell Biol. 6, 85–89.
41 Dai, J., Ting-Beall, H. P., Hochmuth, R. M., Sheetz, M. P. and Titus, M. A. (1999) Myosin I contributes to the generation of resting cortical tension. Biophys. J. 77, 1168–1176.
42 Yang, C., Pring, M., Wear, M. A., Huang, M., Cooper, J. A., Svitkina, T. M. and Zigmond, S. H. (2005) Mammalian

CARMIL inhibits actin filament capping by capping protein. Dev. Cell 9, 209–221.
43 Durrwang, U., Fujita-Becker, S., Erent, M., Kull, F. J., Tsiavaliaris, G., Geeves, M. A. and Manstein, D. J. (2006) *Dictyostelium* myosin-IE is a fast molecular motor involved in phagocytosis. J. Cell Sci. 119, 550–558.
44 Peterson, M. D., Novak, K. D., Reedy, M. C., Ruman, J. I. and Titus, M. A. (1995) Molecular genetic analysis of myoC, a *Dictyostelium* myosin I. J. Cell Sci. 108, 1093–1103.
45 Cheney, C. M., Kravit, N. G. and Verbsky, J. W. (1993) A new myosin I gene in *Drosophila.* Biochem. Biophys. Res. Commun. 195, 1280–1288.
46 Morgan, N. S., Skovronsky, D. M., Artavanis-Tsakonas, S. and Mooseker, M. S. (1994) The molecular cloning and characterization of *Drosophila melanogaster* myosin-IA and myosin-IB. J. Mol. Biol. 239, 347–356.
47 Spéder, P., Ádám, G. and Noselli, S. (2006) Type ID unconventional myosin controls left-right asymmetry in *Drosophila.* Nature 440, 803–807.
48 Hozumi, S., Maeda, R., Taniguchi, K., Kanai, M., Shirakabe, S., Sasamura, T., Speder, P., Noselli, S., Aigaki, T., Murakami, R. and Matsuno, K. (2006) An unconventional myosin in *Drosophila* reverses the default handedness in visceral organs. Nature 440, 798–802.
49 Spéder, P. and Noselli, S. (2007) Left-right asymmetry: Class I myosins show the direction. Curr. Opin. Cell Biol. 19, 82–87.
50 Gillespie, P. G. Albanesi, J. P., Bahler, M., Bement, W. M., Berg, J. S., Burgess, D. R., Burnside, B., Cheney, R. E., Corey, D. P., Coudrier, E., de Lanerolle, P., Hammer, J. A., Hasson, T., Holt, J. R., Hudspeth, A. J., Ikebe, M., Kendrick-Jones, J., Korn, E. D., Li, R., Mercer, J. A., Milligan, R. A., Mooseker, M. S., Ostap, E. M., Petit, C., Pollard, T. D., Sellers, J. R., Soldati, T. and Titus, M. A. (2001) Myosin-I nomenclature. J. Cell Biol. 155, 703–704.
51 Pollard, T. D., Doberstein, S. K. and Zot, H. G. (1991) Myosin-I. Annu. Rev. Physiol. 53, 653–682.
52 Mooseker, M. S. and Cheney, R. E. (1995) Unconventional myosins. Annu. Rev. Cell Dev. Biol. 11, 633–675.
53 Nir Osherov, G. S. M. (2000) *In vivo* function of class I myosins. Cell Motil. Cytoskeleton 47, 163–173.
54 Gillespie, P. G. and Cyr, J. L. (2004) Myosin-1c, the hair cell's adaptation motor. Annu. Rev. Physiol. 66, 521–545.
55 Mooseker, M. S. and Tilney, L. G. (1975) Organization of an actin filament-membrane complex. Filament polarity and membrane attachment in the microvilli of intestinal epithelial cells. J. Cell Biol. 67, 725–743.
56 Matsudaira, P. T. and Burgess, D. R. (1979) Identification and organization of the components in the isolated microvillus cytoskeleton. J. Cell Biol. 83, 667–673.
57 Collins, J. H. and Borysenko, C. W. (1984) The 110,000-dalton actin- and calmodulin-binding protein from intestinal brush border is a myosin-like ATPase. J. Biol. Chem. 259, 14128–14135.
58 Collins, K., Sellers, J. R. and Matsudaira, P. (1990) Calmodulin dissociation regulates brush border myosin I (110-kD-calmodulin) mechanochemical activity *in vitro.* J. Cell Biol. 110, 1137–1147.
59 Swanljung-Collins, H. and Collins, J. H. (1991) Ca^{2+} stimulates the Mg^{2+}-ATPase activity of brush border myosin I with three or four calmodulin light chains but inhibits with less than two bound. J. Biol. Chem. 266, 1312–1319.
60 Donaudy, F., Ferrara, A., Esposito, L., Hertzano, R., Ben-David, O., Bell, R. E., Melchionda, S., Zelante, L., Avraham, K. B. and Gasparini, P. (2003) Multiple mutations of MYO1A, a cochlear-expressed gene, in sensorineural hearing loss. Am. J. Hum. Genet. 72, 1571–1577.
61 Skowron, J. F., Bement, W. M. and Mooseker, M. S. (1998) Human brush border myosin-I and myosin-Ic expression in human intestine and Caco-2BBe cells. Cell Motil. Cytoskeleton 41, 308–324.
62 Hayden, S. M., Wolenski, J. S. and Mooseker, M. S. (1990) Binding of brush border myosin I to phospholipid vesicles. J. Cell Biol. 111, 443–451.
63 Zot, H. G. (1995) Phospholipid membrane-associated brush border myosin-I activity. Cell Motil. Cytoskeleton 30, 26–37.
64 Bikle, D. D., Munson, S., Morrison, N. and Eisman, J. (1993) Zipper protein, a newly described tropomyosin-like protein of the intestinal brush border. J. Biol. Chem. 268, 620–626.
65 Tyska, M. J., Mackey, A. T., Huang, J. D., Copeland, N. G., Jenkins, N. A. and Mooseker, M. S. (2005) Myosin-1a is critical for normal brush border structure and composition. Mol. Biol. Cell 16, 2443–2457.
66 Fath, K. R. and Burgess, D. R. (1993) Golgi-derived vesicles from developing epithelial cells bind actin filaments and possess myosin-I as a cytoplasmically oriented peripheral membrane protein. J. Cell Biol. 120, 117–127.
67 Fath, K. R., Trimbur, G. M. and Burgess, D. R. (1994) Molecular motors are differentially distributed on Golgi membranes from polarized epithelial cells. J. Cell Biol. 126, 661–675.
68 McConnell, R. E. and Tyska, M. J. (2007) Myosin-1a powers the sliding of apical membrane along microvillar actin bundles. J. Cell Biol. 177, 671–681.
69 Ruppert, C., Kroschewski, R. and Bahler, M. (1993) Identification, characterization and cloning of myr 1, a mammalian myosin-I. J. Cell Biol. 120, 1393–1403.
70 Sherr, E. H., Joyce, M. P. and Greene, L. A. (1993) Mammalian myosin I alpha, I beta, and I gamma: New widely expressed genes of the myosin I family. J. Cell Biol. 120, 1405–1416.
71 Perreault-Micale, C., Shushan, A. D. and Coluccio, L. M. (2000) Truncation of a mammalian myosin I results in loss of Ca^{2+}-sensitive motility. J. Biol. Chem. 275, 21618–21623.
72 Tang, N. and Ostap, E. M. (2001) Motor domain-dependent localization of myo1b (myr-1). Curr. Biol. 11, 1131–1135.
73 Lewis, A. K. and Bridgman, P. C. (1996) Mammalian myosin I alpha is concentrated near the plasma membrane in nerve growth cones. Cell Motil. Cytoskeleton 33, 130–150.
74 Cordonnier, M.-N., Dauzonne, D., Louvard, D. and Coudrier, E. (2001) Actin filaments and myosin I alpha cooperate with microtubules for the movement of lysosomes. Mol. Biol. Cell 12, 4013–4029.
75 Barylko, B., Wagner, M. C., Reizes, O. and Albanesi, J. P. (1992) Purification and characterization of a mammalian myosin I. Proc. Natl. Acad. Sci. USA 89, 490–494.
76 Metclaf, A. B., Chelliah, Y. and Hudspeth, A. J. (1994) Molecular cloning of a myosin Ibeta isozyme that may mediate adaptation by hair cells of the bullfrog's internal ear. Proc. Natl. Acad. Sci. USA 91, 11821–11825.
77 Reizes, O., Barylko, B., Li, C., Sudhof, T. C. and Albanesi, J. P. (1994) Domain structure of a mammalian myosin Ibeta. Proc. Natl. Acad. Sci. USA 91, 6349–6353.
78 Zhu, T. and Ikebe, M. (1994) A novel myosin I from bovine adrenal gland. FEBS Lett. 339, 31–36.
79 Zhu, T., Sata, M. and Ikebe, M. (1996) Functional expression of mammalian myosin Ibeta: Analysis of Its motor activity. Biochemistry 35, 513–522.
80 Zhu, T., Beckingham, K. and Ikebe, M. (1998) High affinity Ca^{2+} binding sites of calmodulin are critical for the regulation of myosin Ibeta motor function. J. Biol. Chem. 273, 20481–20486.
81 Wagner, M. C., Barylko, B. and Albanesi, J. P. (1992) Tissue distribution and subcellular localization of mammalian myosin I. J. Cell Biol. 119, 163–170.
82 Ruppert, C., Godel, J., Muller, R. T., Kroschewski, R., Reinhard, J. and Bahler, M. (1995) Localization of the rat myosin I molecules myr 1 and myr 2 and *in vivo* targeting of their tail domains. J. Cell Sci. 108, 3775–3786.
83 Allen, L. H. and Aderem, A. (1995) A role for MARCKS, the alpha isozyme of protein kinase C and myosin I in zymosan phagocytosis by macrophages. J. Exp. Med. 182, 829–840.
84 Gillespie, P. G., Wagner, M. C. and Hudspeth, A. J. (1993) Identification of a 120 kd hair-bundle myosin located near stereociliary tips. Neuron 11, 581–594.

85 Hasson, T., Gillespie, P. G., Garcia, J. A., MacDonald, R. B., Zhao, Y.-D., Yee, A. G., Mooseker, M. S. and Corey, D. P. (1997) Unconventional myosins in inner-ear sensory epithelia. J. Cell Biol. 137, 1287–1307.
86 Gillespie, P. G. and Corey, D. P. (1997) Myosin and adaptation by hair cells. Neuron 19, 955–958.
87 Gillespie, P. G., Gillespie, S. K. H., Mercer, J. A., Shah, K. and Shokat, K. M. (1999) Engineering of the myosin-Ibeta nucleotide-binding pocket to create selective sensitivity to N6-modified ADP analogs. J. Biol. Chem. 274, 31373–31381.
88 Holt, J. R., Gillespie, S. K., Provance, D. W., Shah, K., Shokat, K. M., Corey, D. P., Mercer, J. A. and Gillespie, P. G. (2002) A chemical-genetic strategy implicates myosin-1c in adaptation by hair cells. Cell 108, 371–381.
89 Cyr, J. L., Dumont, R. A. and Gillespie, P. G. (2002) Myosin-1c Interacts with hair-cell receptors through Its calmodulin-binding IQ domains. J. Neurosci. 22, 2487–2495.
90 Phillips, K. R., Tong, S., Goodyear, R., Richardson, G. P. and Cyr, J. L. (2006) Stereociliary myosin-1c receptors are sensitive to calcium chelation and absent from cadherin 23 mutant mice. J. Neurosci. 26, 10777–10788.
91 Hokanson, D. E., Laakso, J. M., Lin, T., Sept, D. and Ostap, E. M. (2006) Myo1c binds phosphoinositides through a putative pleckstrin homology domain. Mol. Biol. Cell 17, 4856–4865.
92 Siemens, J., Lillo, C., Dumont, R. A., Reynolds, A., Williams, D. S., Gillespie, P. G. and Muller, U. (2004) Cadherin 23 is a component of the tip link in hair-cell stereocilia. Nature 428, 950–955.
93 Bose, A., Guilherme, A., Robida, S. I., Nicoloro, S. M., Zhou, Q. L., Jiang, Z. Y., Pomerleau, D. P. and Czech, M. P. (2002) Glucose transporter recycling in response to insulin is facilitated by myosin Myo1c. Nature 420, 821–824.
94 Sokac, A. M., Schietroma, C., Gundersen, C. B. and Bement, W. M. (2006) Myosin-1c couples assembling actin to membranes to drive compensatory endocytosis. Dev. Cell 11, 629–640.
95 Nowak, G., Pestic-Dragovich, L., Hozak, P., Philimonenko, A., Simerly, C., Schatten, G. and de Lanerolle, P. (1997) Evidence for the presence of myosin I in the nucleus. J. Biol. Chem. 272, 17176–17181.
96 Pestic-Dragovich, L., Stojiljkovic, L., Philimonenko, A. A., Nowak, G., Ke, Y., Settlage, R. E., Shabanowitz, J., Hunt, D. F., Hozak, P. and de Lanerolle, P. (2000) A myosin I isoform in the nucleus. Science 290, 337–341.
97 Philimonenko, V. V., Zhao, J., Iben, S., Dingova, H., Kysela, K., Kahle, M., Zentgraf, H., Hofmann, W. A., de Lanerolle, P., Hozak, P. and Grummt, I. (2004) Nuclear actin and myosin I are required for RNA polymerase I transcription. Nat. Cell Biol. 6, 1165–1172.
98 Hofmann, W. A., Johnson, T., Klapczynski, M., Fan, J. L. and de Lanerolle, P. (2006) From transcription to transport: Emerging roles for nuclear myosin I. Biochem. Cell Biol. 84, 418–426.
99 Percipalle, P., Fomproix, N., Cavellan, E., Voit, R., Reimer, G., Kruger, T., Thyberg, J., Scheer, U., Grummt, I. and Farrants, A. K. (2006) The chromatin remodelling complex WSTF-SNF2 h interacts with nuclear myosin 1 and has a role in RNA polymerase I transcription. EMBO Rep. 7, 525–530.
100 Kyselá, K., Philimonenko, A., Philimonenko, V., Janáček, J., Kahle, M. and Hozák, P. (2005) Nuclear distribution of actin and myosin I depends on transcriptional activity of the cell. Histochem. Cell Biol. 124, 347–358.
101 Chuang, C.-H., Carpenter, A. E., Fuchsova, B., Johnson, T., de Lanerolle, P. and Belmont, A. S. (2006) Long-range directional movement of an interphase chromosome site. Curr. Biol. 16, 825–831.
102 Coluccio, L. M. (1994) Differential calmodulin binding to three myosin-1 isoforms from liver. J. Cell Sci. 107, 2279–2284.
103 Bahler, M., Kroschewski, R., Stoffler, H. E. and Behrmann, T. (1994) Rat myr 4 defines a novel subclass of myosin I: Identification, distribution, localization, and mapping of calmodulin-binding sites with differential calcium sensitivity. J. Cell Biol. 126, 375–389.
104 Kohler, D., Struchholz, S. and Bahler, M. (2005) The two IQ-motifs and Ca^{2+}/calmodulin regulate the rat myosin 1d ATPase activity. FEBS J. 272, 2189–2197.
105 Huber, L. A., Fialka, I., Paiha, K., Hunziker, W., Sacks, D. B., Bahler, M., Way, M., Gagescu, R. and Gruenberg, J. (2000) Both calmodulin and the unconventional myosin Myr4 regulate membrane trafficking along the recycling pathway of MDCK cells. Traffic 1, 494–503.
106 Bement, W. M., Wirth, J. A. and Mooseker, M. S. (1994) Cloning and mRNA expression of human unconventional myosin-IC. A homologue of amoeboid myosins-I with a single IQ motif and an SH3 domain. J. Mol. Biol. 243, 356–363.
107 Stoffler, H. E., Ruppert, C., Reinhard, J. and Bahler, M. (1995) A novel mammalian myosin I from rat with an SH3 domain localizes to Con A-inducible, F-actin-rich structures at cell-cell contacts. J. Cell Biol. 129, 819–830.
108 Bement, W. M., Hasson, T., Wirth, J. A., Cheney, R. E. and Mooseker, M. S. (1994) Identification and overlapping expression of multiple unconventional myosin genes in vertebrate cell types. Proc. Natl. Acad. Sci. USA 91, 6549–6553.
109 Edgar, A. J., Knight, A. E. and Bennett, J. P. (1996) Chicken myosin IB mRNA is highly expressed in lymphoid tissues. J. Anat. 189, 451–456.
110 Crozet, F., Amraoui, A. E., Blanchard, S., Lenoir, M., Ripoll, C., Vago, P., Hamel, C., Fizames, C., Levi-Acobas, F. and Depetris, D. (1997) Cloning of the genes encoding two murine and human cochlear unconventional type I myosins. Genomics 40, 332–341.
111 Kim, S. V., Mehal, W. Z., Dong, X., Heinrich, V., Pypaert, M., Mellman, I., Dembo, M., Mooseker, M. S., Wu, D. and Flavell, R. A. (2006) Modulation of cell adhesion and motility in the immune system by Myo1 f. Science 314, 136–139.
112 Borregaard, N. and Cowland, J. B. (1997) Granules of the human neutrophilic polymorphonuclear leukocyte. Blood 89, 3503–3521.
113 Burgoyne, R. D. and Morgan, A. (2003) Secretory granule exocytosis. Physiol. Rev. 83, 581–632.
114 Ehre, C., Rossi, A. H., Abdullah, L. H., De Pestel, K., Hill, S., Olsen, J. C. and Davis, C. W. (2005) Barrier role of actin filaments in regulated mucin secretion from airway goblet cells. Am. J. Physiol. Cell Physiol. 288, C46–56.
115 Evans, E. and Yeung, A. (1989) Apparent viscosity and cortical tension of blood granulocytes determined by micropipet aspiration. Biophys. J. 56, 151–160.
116 Herant, M., Heinrich, V. and Dembo, M. (2005) Mechanics of neutrophil phagocytosis: Behavior of the cortical tension. J. Cell Sci. 118, 1789–1797.
117 Taki, T., Akiyama, M., Saito, S., Ono, R., Taniwaki, M., Kato, Y., Yuza, Y., Eto, Y. and Hayashi, Y. (2005) The MYO1F, unconventional myosin type 1F, gene is fused to MLL in infant acute monocytic leukemia with a complex translocation involving chromosomes 7, 11, 19 and 22. Oncogene 24, 5191–5197.
118 Chen, A. H., Stephan, D. A., Hasson, T., Fukushima, K., Nelissen, C. M., Chen, A. F., Jun, A. I., Ramesh, A., Van Camp, G. and Smith, R. J. (2001) MYO1F as a candidate gene for nonsyndromic deafness, DFNB15. Arch. Otolaryngol. Head Neck Surg. 127, 921–925.
119 Stoffler, H. E. and Bahler, M. (1998) The ATPase activity of Myr3, a rat myosin I, is allosterically inhibited by its own tail domain and by Ca^{2+} binding to its light chain calmodulin. J. Biol. Chem. 273, 14605–14611.
120 Stoffler, H., Honnert, U., Bauer, C., Hofer, D., Schwarz, H., Muller, R., Drenckhahn, D. and Bahler, M. (1998) Targeting of the myosin-I myr 3 to intercellular adherens type junctions induced by dominant active Cdc42 in HeLa cells. J. Cell Sci. 111, 2779–2788.

121 Diakonova, M., Bokoch, G. and Swanson, J. A. (2002) Dynamics of cytoskeletal proteins during Fcgamma receptor-mediated phagocytosis in macrophages. Mol. Biol. Cell 13, 402–411.
122 Swanson, J. A., Johnson, M. T., Beningo, K., Post, P., Mooseker, M. and Araki, N. (1999) A contractile activity that closes phagosomes in macrophages. J. Cell Sci. 112, 307–316.
123 Krendel, M., Osterweil, E. K. and Mooseker, M. S. (2007) Myosin 1E interacts with synaptojanin-1 and dynamin and is involved in endocytosis. FEBS Lett. 581, 644–650.
124 Dumont, R. A., Zhao, Y.-D., Holt, J. R., Bähler, M. and Gillespie, P. G. (2002) Myosin-I isozymes in neonatal rodent auditory and vestibular epithelia. J. Assoc. Res. Otolaryngol. 3, 375–389.