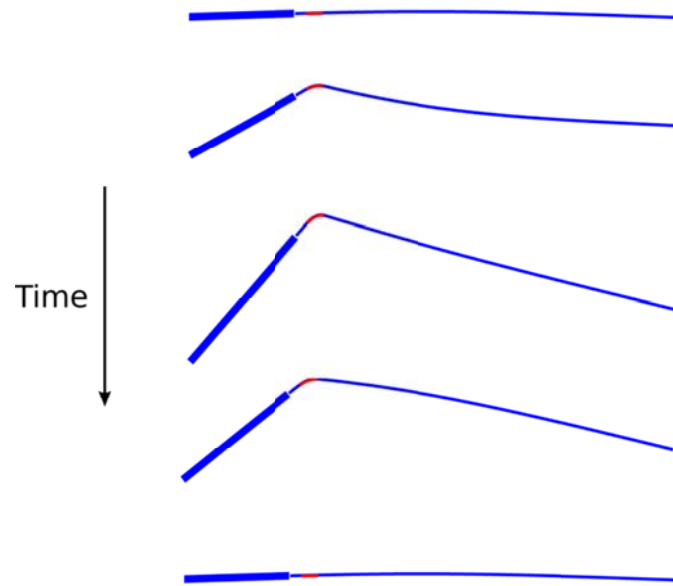
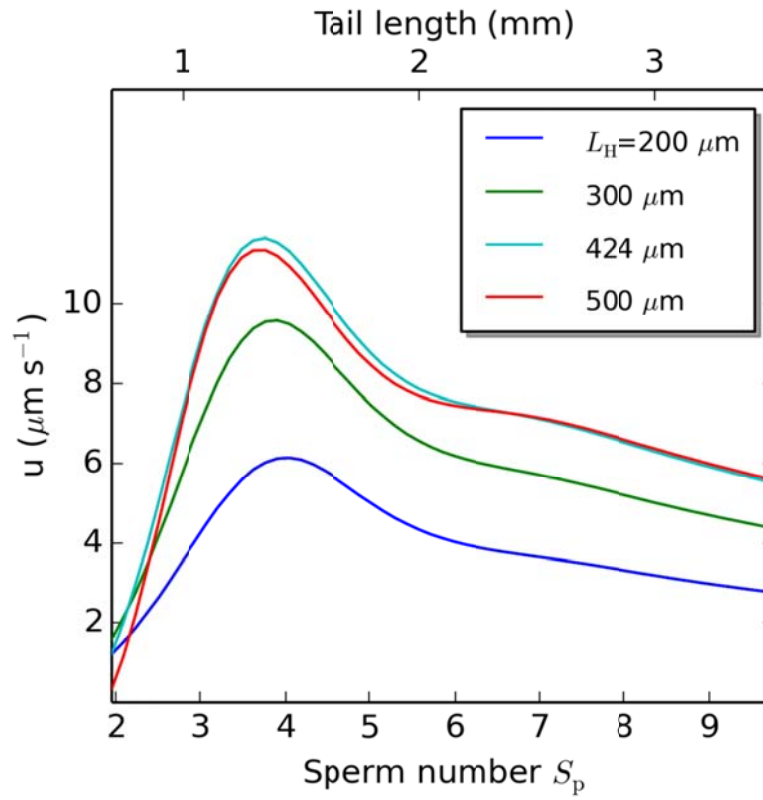
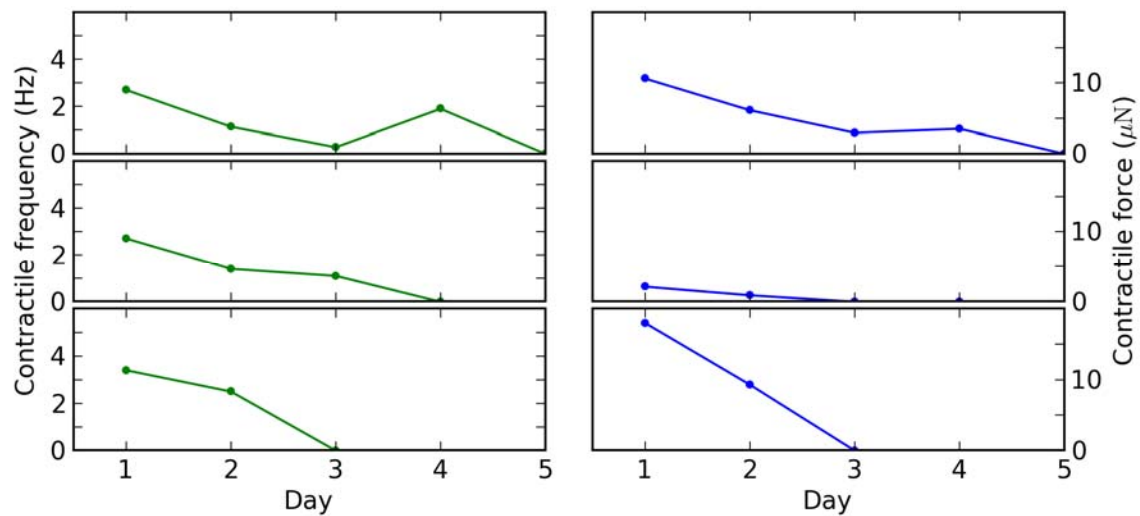




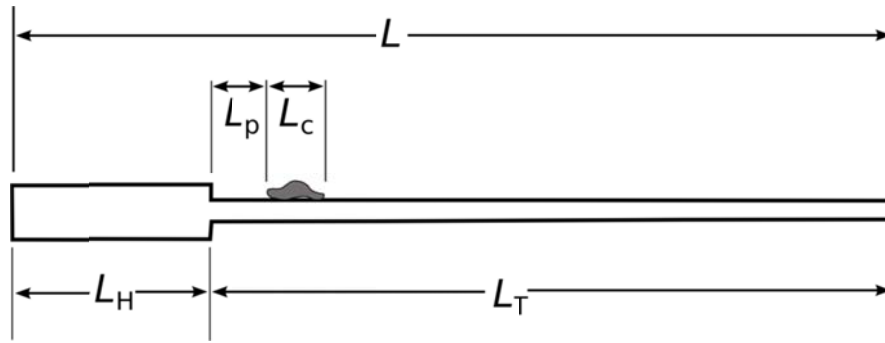
Supplementary Figure 1. Sample filament displacement curves predicted by solving the elastohydrodynamic model. The red region indicates the location of cardiomyocytes driving the system. The deformation of the thin region in response to fluid drag yields the time irreversibility that produces a net propulsive force.



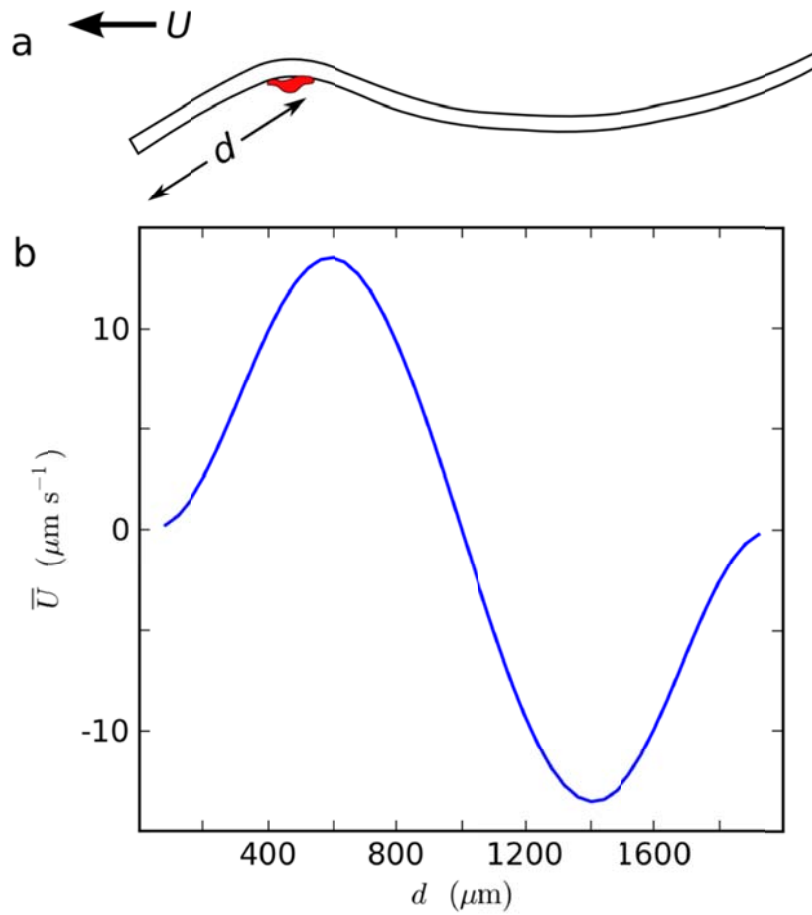
Supplementary Figure 2. Effect of Sperm number on swimming velocity. The Sperm number (bottom axis) and the corresponding tail length (top axis) are varied for head lengths L_H of 200 μm , 300 μm , 424 μm (the head length of swimmer 1 in Supplementary Table 1), and 500 μm , predicting an optimum swimming velocity for a Sperm number of approximately 4.



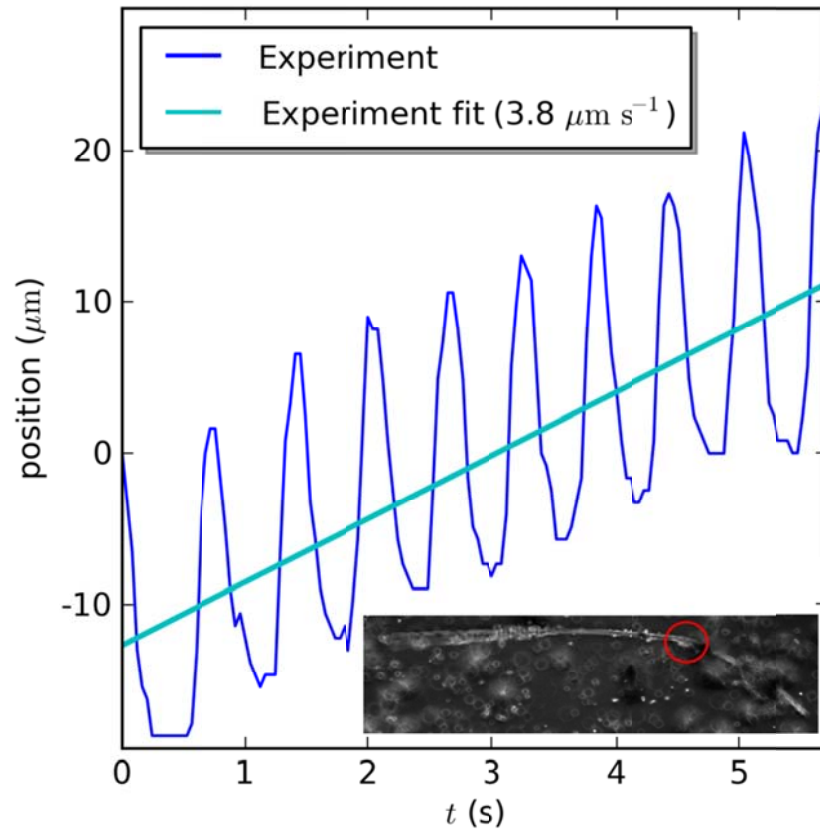
Supplementary Figure 3. Lifetime of biohybrid actuator. Several samples are observed for several days to show the persistence of contractile force and frequency. Tails are cut on Day 0, and observed daily. All samples are maintained at 37°C in cell culture media.



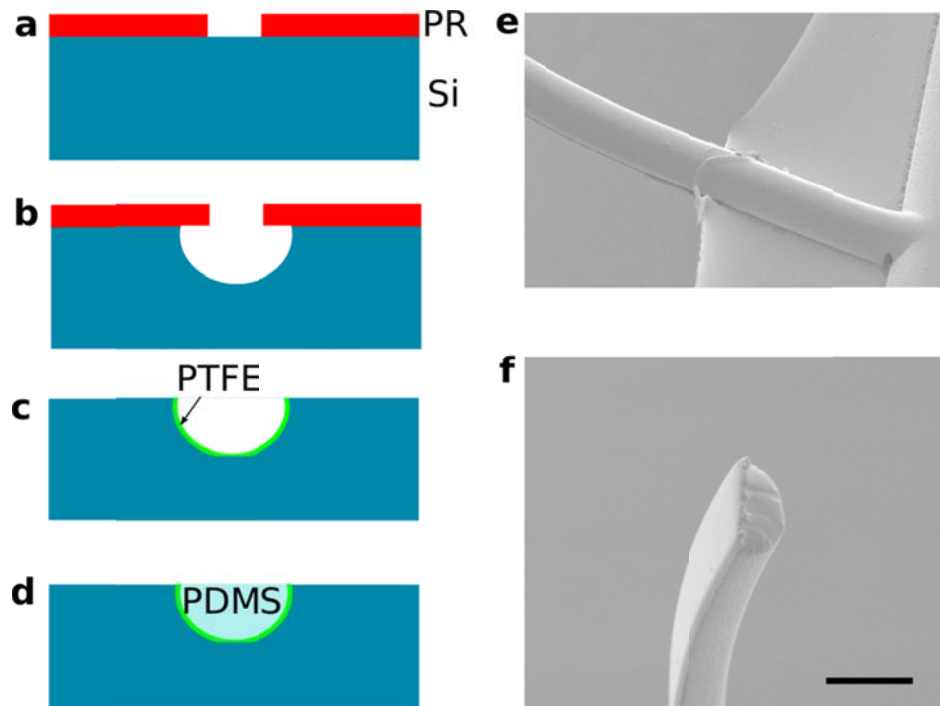
Supplementary Figure 4. Definition of geometric parameters. We define the relevant variables required as inputs to the elastohydrodynamic model and used to characterize the specimens tabulated in Supplementary Table 1.



Supplementary Figure 5. Effect of cell placement on swimming direction. We predict swimming dynamics on a homogenous filament without a head. (a) We vary the distance d of a single actuator from one end of the filament. (b) The resultant predicted swimming velocity displays symmetric maxima in either direction, demonstrating the potential to swim either forwards or backwards using a filament with multiple actuation sites.



Supplementary Figure 6. Backwards swimming. We demonstrate backwards swimming by culturing cells near the tail end of the swimmer (see swimmer 5 in Supplementary Table 1).



Supplementary Figure 7. Fabrication of a non-rectangular cross section. (a-d) Fabrication steps, where PR is photoresist, Si is the silicon substrate, and PTFE is polytetrafluoroethylene. At (b), silicon is etched isotropically by sulfur hexafluoride (SF_6). At (d), the channel is filled with liquid PDMS by capillary draw, followed by curing at 60°C . (e-f) Scanning electron micrographs of the PDMS filament and round cross-section.

Sample	v_{exp} ($\mu\text{m s}^{-1}$)	v_{model} ($\mu\text{m s}^{-1}$)	$v_{\text{exp}} L^{-1}$ (s^{-1})	L (μm)	L_{T} (μm)	L_{H} (μm)	L_{p} (μm)	L_{c} (μm)	F_{cell} (μN)	f_{cell} (Hz)	Re ($\times 10^{-3}$)	S_{p}
1	9.7	11.0	.0050	1927	1503	424	45	60	7.5	3.6	18.0	4.19
2	4.0	4.8	.0024	1637	1062	575	0	72	14.4	2.5	7.0	2.2
3	5.8	3.8	.0027	2160	1791	369	0	101	8.7	1.68	13.5	3.4
4	4.6	2.8	.0030	1551	1182	369	0	101	8.0	2.55	7.7	2.6
5	-3.8	-1.8	.0016	2211	1663	548	931	78	4.4	1.6	9.1	3.3

Supplementary Table 1. Parameters for sample swimmers. Relevant geometric and dynamic parameters for the 5 swimmers illustrated in Fig. 5 are tabulated. Geometric parameters are defined in Supplementary Fig. 4. v_{exp} , v_{model} , and $v_{\text{exp}} L^{-1}$ represent observed, predicted, and scaled velocities, respectively. F_{cell} is the peak force generated by the cell, and f_{cell} is the mean driving frequency in Hz. Re is the Reynolds number, and S_{p} is the sperm number computed as $L \left(\frac{\zeta_{\perp} \omega}{A} \right)^{\frac{1}{4}}$, where A is the filament stiffness and $\zeta_{\perp}$ is the normal drag coefficient of the filament, and ω is the actuating frequency in radians s^{-1} . Sample 5 demonstrates backwards swimming, indicated by negative velocities (see Supplementary Fig. 6).