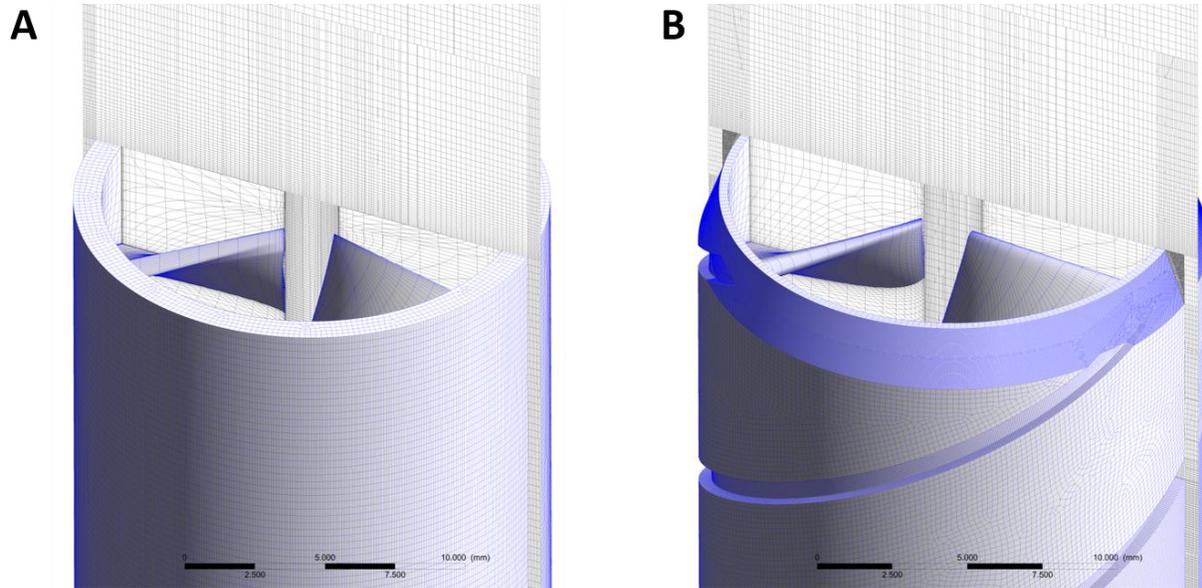Supplementary Material


Fig S1. Mesh images for Mod 1 and Mod 2. The mesh consists of 4,418,397 elements and 13,299,271elements for Mod 1 and Mod 2 respectively. The meshing of Mod 2 required more mesh regions to ensure a sufficient mesh quality in the gap, the additional chamfers, the troughs on the outside, and the roundings at the leading edge; these additional features resulted in larger elements.
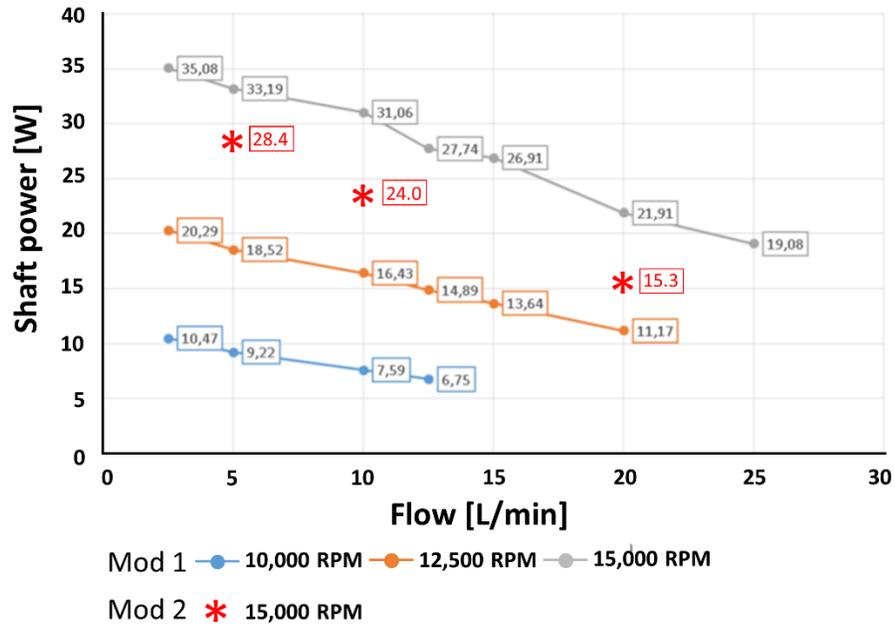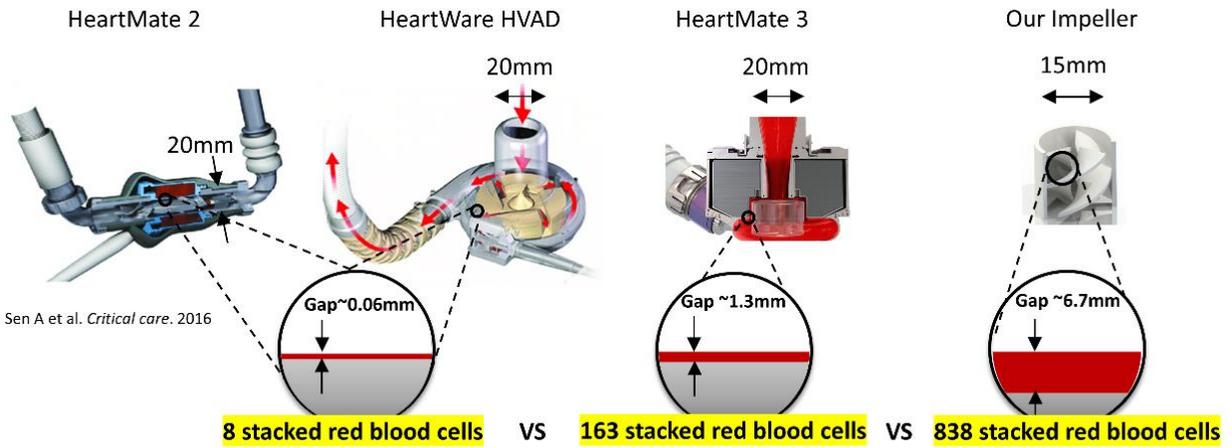
Fig S2. Shaft power resulted from Mod 1 and Mod 2. Shaft power is an integral of hydraulic power plotted in Fig 7 as a variable over the blade surfaces which visualizes the efficiency of the flow guidance and highlights areas where hydraulic losses occur.
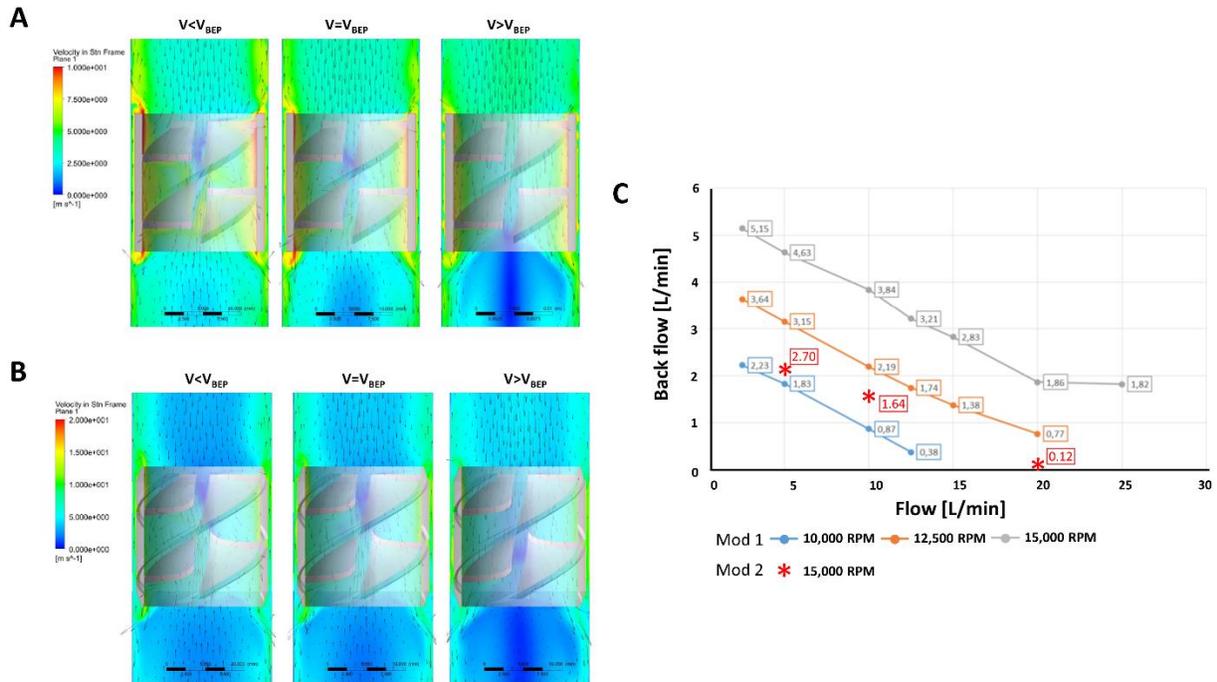
Fig S3. Flow field and quantified backflow. (A) Flow field within Mod 1 when the pump flow (V) is below (V<V$_{BEP}$), at (V=V$_{BEP}$), and above (V>V$_{BEP}$) the best efficiency point (BEP) for 12,500 RPM. (B) Flow field within Mod 2 when the pump flow (V) is below (V<V$_{BEP}$), at (V=V$_{BEP}$), and above (V>V$_{BEP}$) the BEP for 15,000 RPM. (C) Quantified backflow within Mod 1 and 2. The implementation of the troughs on the BiO-H impeller bushing in Mod 2 significantly decreased the secondary gap backflow compared to Mod 1.
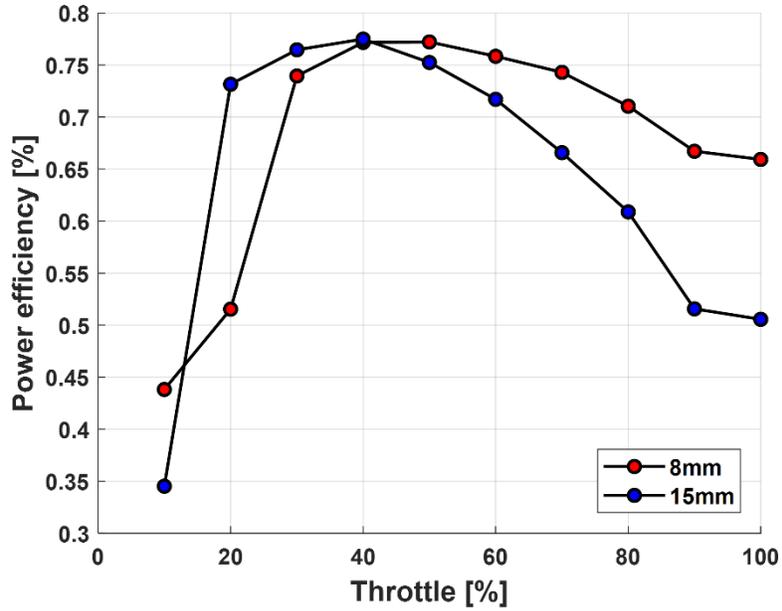
**Fig S4. Power efficiency measurements.** Voltage and current were measured at motor terminals

for each throttle to calculate power efficiency by following Eq 2. The small and large pump

prototypes show different power efficiency profiles although the same motor has been used due

to the load differences between the two.

HeartMate 2   HeartWare HVAD   HeartMate 3   Our Impeller

20mm   20mm   15mm

20mm

Sen A et al. *Critical care.* 2016

Gap~0.06mm   Gap ~1.3mm   Gap ~6.7mm

8 stacked red blood cells   VS   163 stacked red blood cells   VS   838 stacked red blood cells

Fig S5. Blood flow gap size comparison. The number of blood cells that can be stacked inside the BiO-H is 838 compared to 8 and 163 for the HeartMate 2 (Abbott, Chicago, IL) or HeartWare HVAD (Medtronic, Minneapolis, MN) and HeartMate 3 (Abbott, Chicago, IL).

	Conventional Impeller design	BiO-H
	12 mm	15 mm
Occluded cross-sectional area (gray)	98.81 mm²	70.25 mm²
Cross-sectional area loss	87.37 %	39.75 %
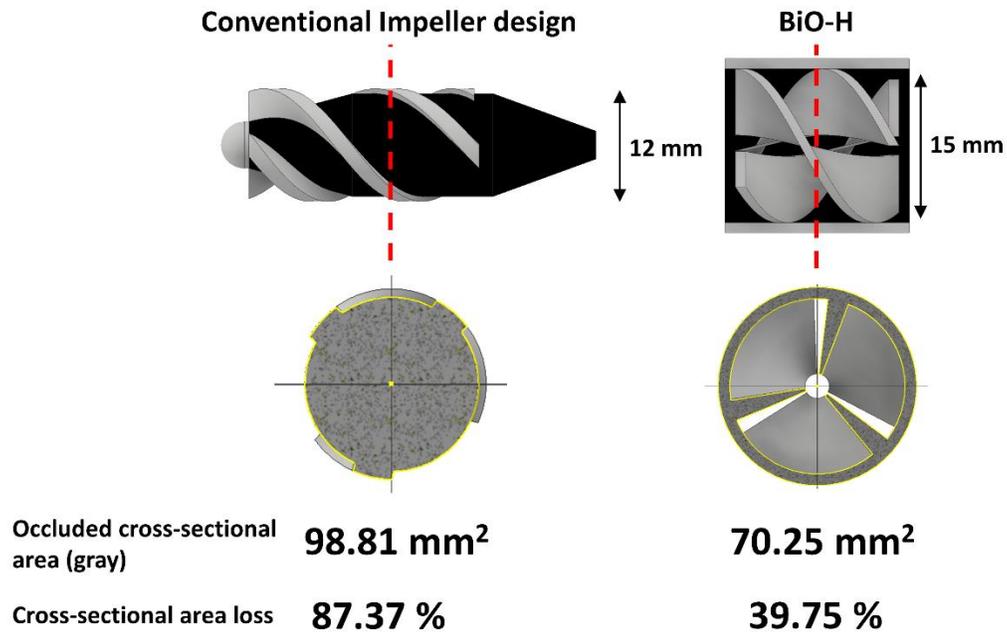
Fig S6. Occluded cross-sectional area comparison. BiO-H shows 2.25-fold less cross-sectional area loss than the conventional impeller design (e.g. HeartMate II)
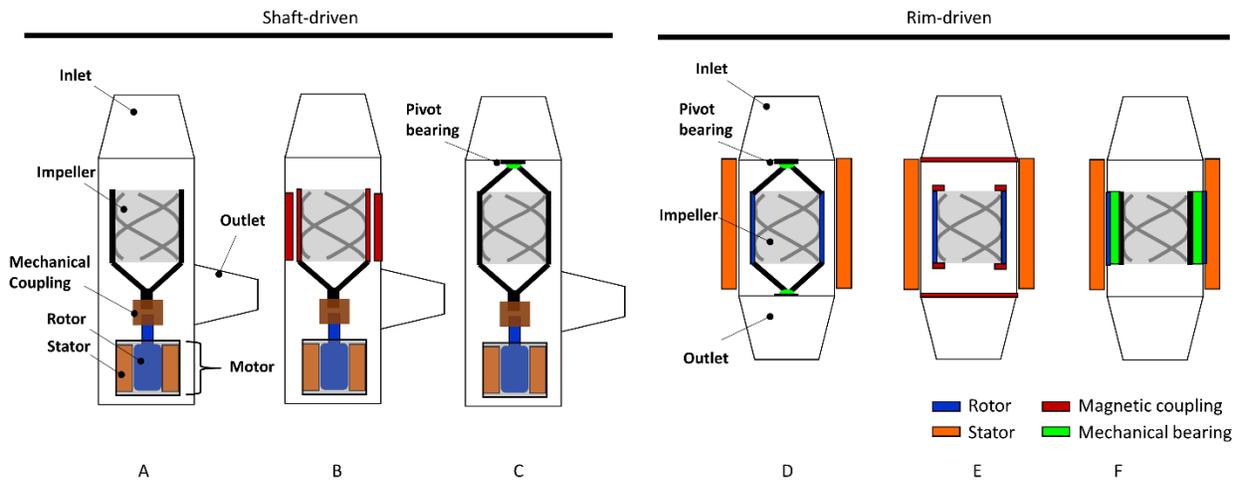
Fig S7. Actuation mechanism. (A) Shaft-driven mechanism with mechanical coupling. (B) Shaft-driven mechanism combined with magnetic coupling. (C) Shaft-driven mechanism combined with pivot bearing. (D) Rim-driven mechanism with pivot bearings. (E) Rim-driven mechanism with a fully magnetically levitated system. (F) Rim-driven mechanism with a structurally integrated mechanical bearing between impeller and housing.