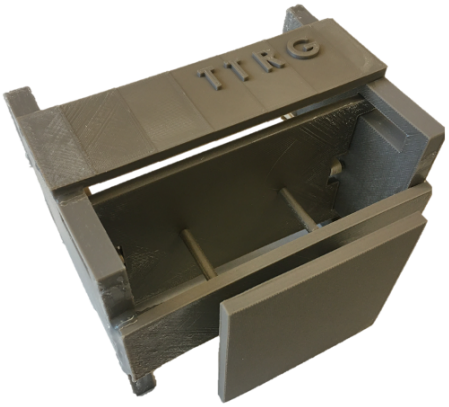
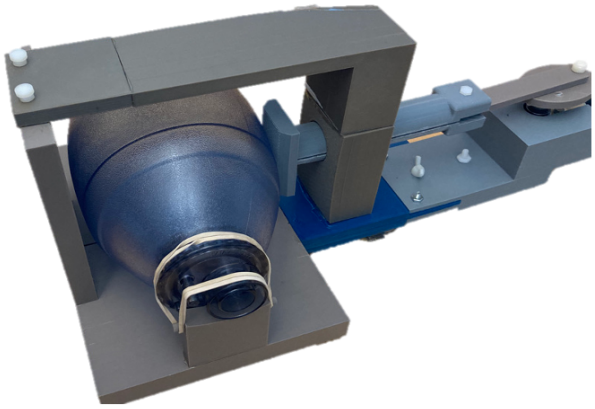
User Manual

Respiratory Motion Simulator





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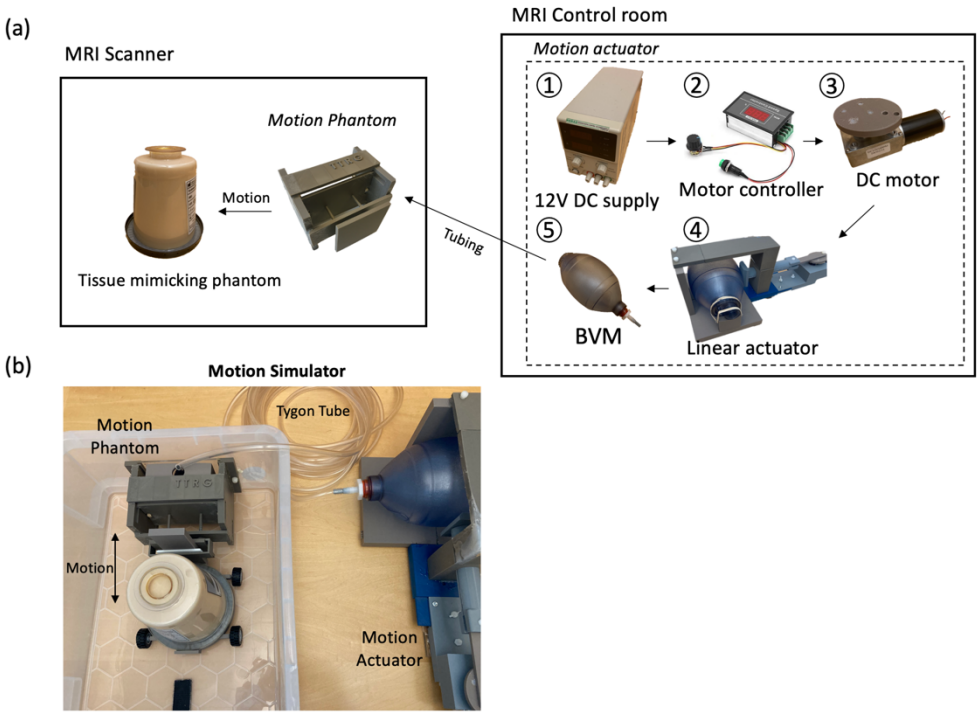
1. Overview of mechanisms

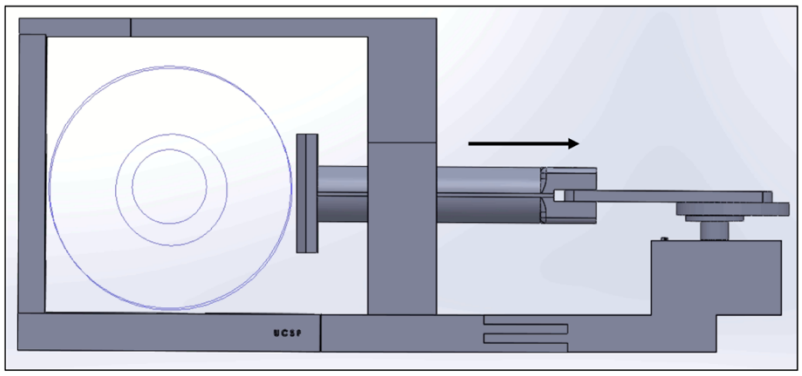
Outside the MRI suite, a DC motor of 16 rpm is connected to a motion actuator, which increases or decreases the pressure inside the BVM. The BVM is coupled via Tygon tubing to the compressible bag in the motion phantom in the MRI scanner. Various levels of inflation or deflation of the BVM cause cyclical motion of tissue-mimicking phantom in the MRI scanner to simulate the shift of abdominal organs due to respiratory motion. The motor controller allowed adjusting the speed of the DC motor in the range of 8-16 cycles per minute.



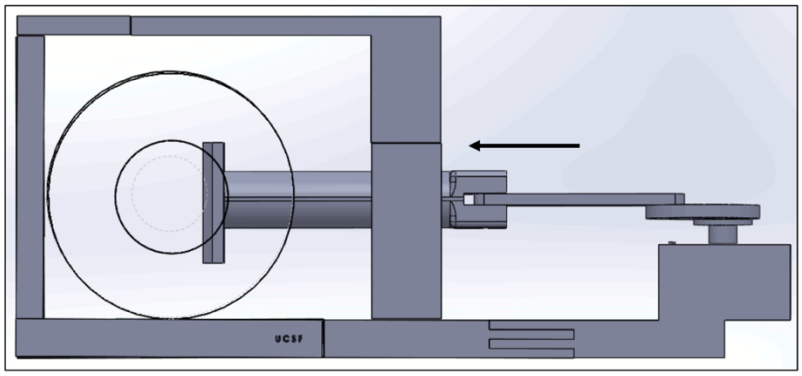
Designed respiratory motion simulator. (a) A schematic diagram and (b) a photo of the phantom and actuator.

Motion actuator mechanisms

Exhalation



Inhalation



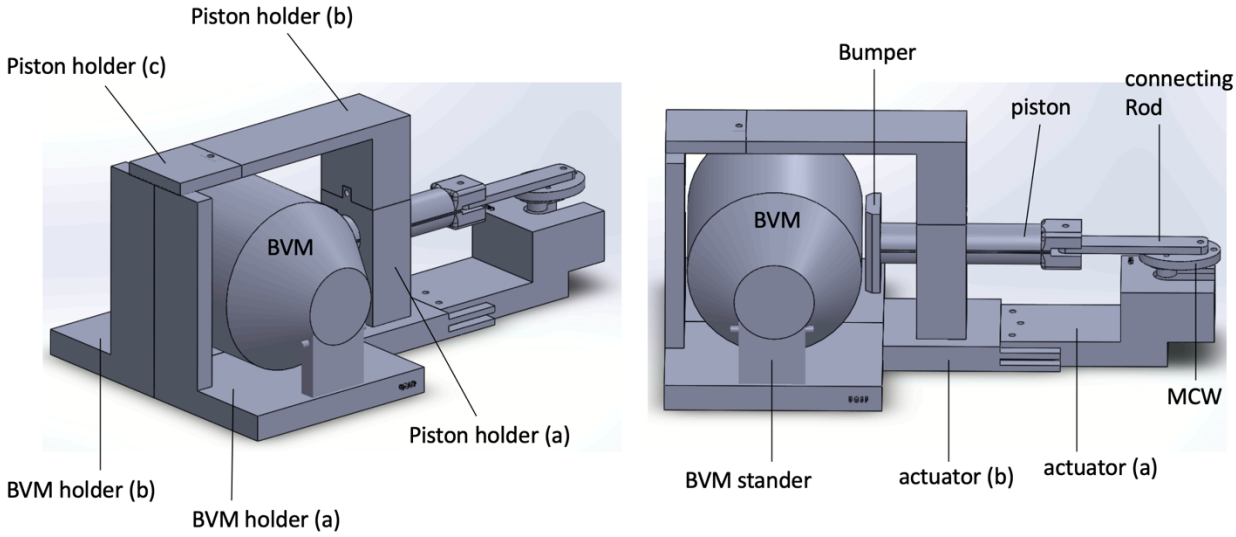
The motion actuator was constructed of a DC motor, 3D-printed linear actuator, and the BVM. The linear actuator was connected to the DC motor to convert the motor rotation into linear motion. The motion of the actuator controlled the level of inflation or deflation of the BVM.

2. List of components

Name	Info	Cost
DC Power Supply	Korad Technology KD3005D, DC Linear Power Supply	$85
DC motor	Brand: Bringsmart (Amazon), 12V-16 rpm, gear motor 70kg·cm	$30
DC motor speed controller	Brand: Vikye (Amazon), 6-60V, 30A PWM motor controller	$15
8 mm Flange shaft coupling motor connector	Brand: Magic&shell, Thread size: M4, Material: Metal	$11
Bag Valve Mask (BVM)	Brand: NEcommerce (currently not available) **Package Dimensions:** 25.65 x 17.78 x 11.43 cm; 454 g, volume 1.8 L	<$50
Reservoir bag for the BVM	Brand: NEcommerce (currently not available)	
Tygon Tubing	Brand: Masterflex, 15ft	<$26
3D printer	Zortrax-M200 Plus	-
3D printing material	Acrylonitrile Butadiene Styrene (ABS)	$21/1kg
Epoxy Glue	Brand: Gorilla Glue Epoxy	$11
Motion Actuator		**Weight**
Motor connector coupling wheel (MCW)	3D-printed	12 g
Connecting Rod	3D-printed	10 g
Piston	3D-printed	53 g
Piston holder (a)	3D-printed	83 g
Piston holder (b)	3D-printed	110 g
Piston holder (c)	3D-printed	24 g
Bumper	3D-printed	15 g
Actuator (a)	3D-printed	170 g
Actuator (b)	3D-printed	122 g
BVM stander	3D-printed	16 g
BVM holder (a)	3D-printed	227 g
BVM holder (b)	3D-printed	227 g
Motion Phantom		
Part (a)	3D-printed	50 g
Part (b)	3D-printed	50 g
Part (c)	3D-printed	21 g
Part (d)	3D-printed	22 g
Pusher (a)	3D-printed	38 g
Pusher (b)	3D-printed	25 g
Back cover	3D-printed	39 g

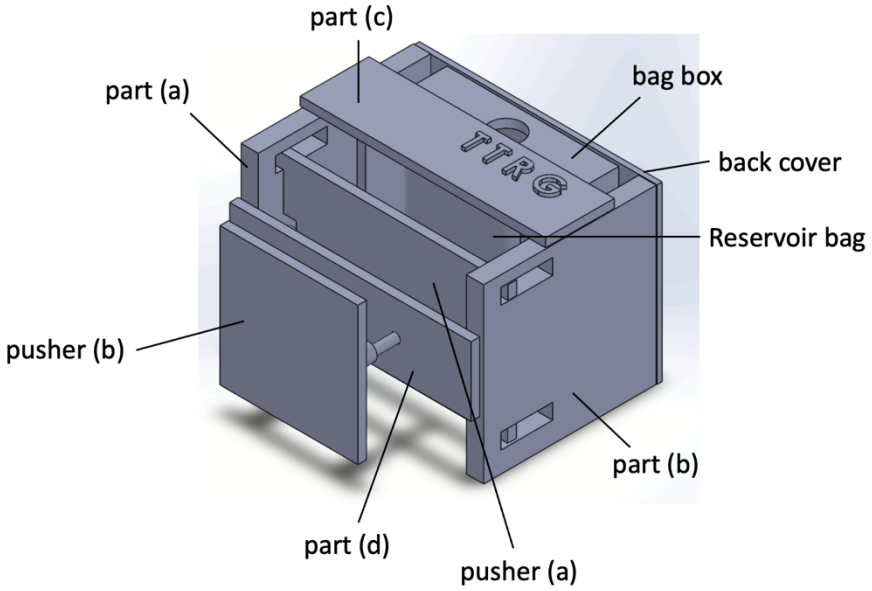
Bag box	3D-printed	75 g
Total amount	(Total 3D printing materials 1.4 kg x $21) + $ 228 = **$ 257**	

Motion actuator components

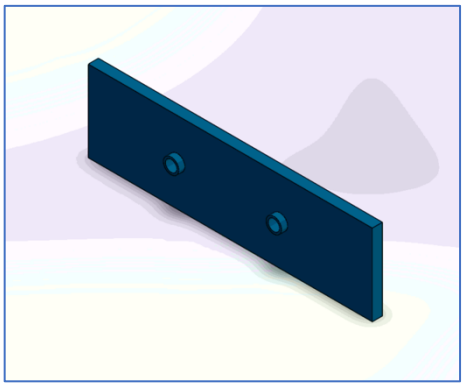


- MCW: Motor Coupling Wheel
- BVM: Bag Valve Mask

Motion Phantom components

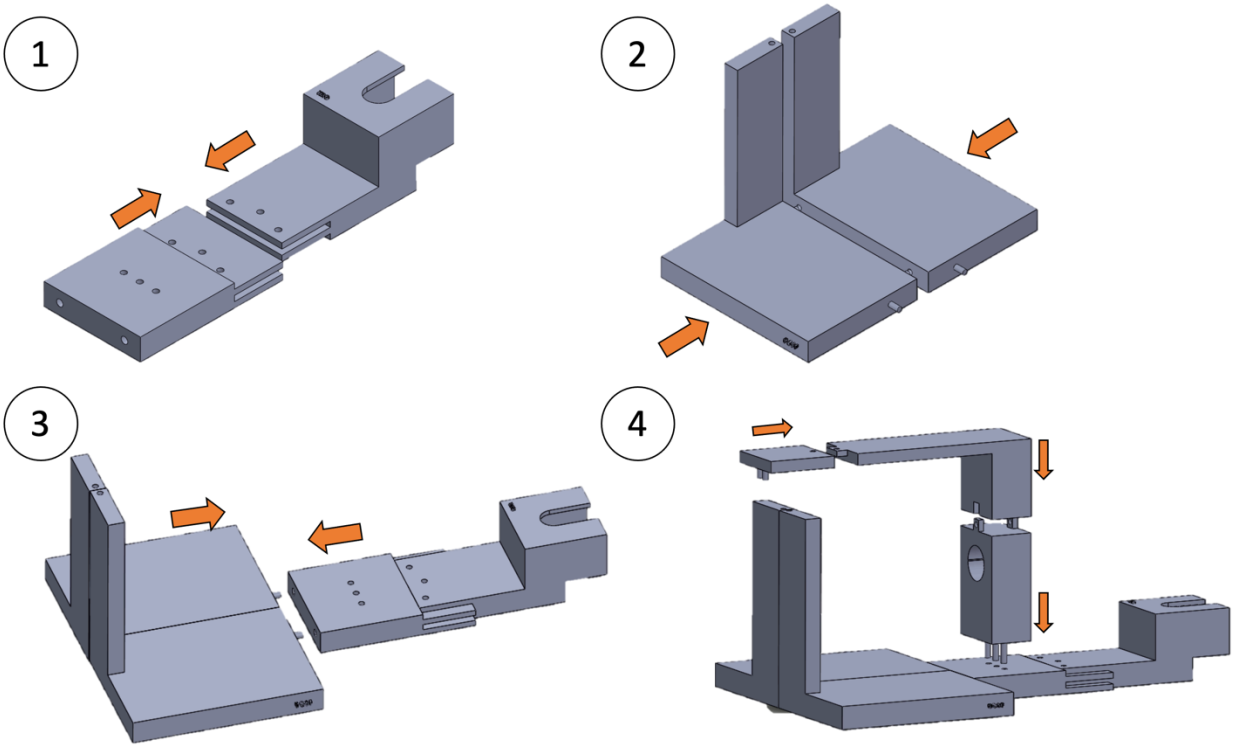


*Part (d) (modified 03/10/2022): This model has been updated to have a chamfer for a more stable movement.



3. Assembly order

- **Motion Actuator**



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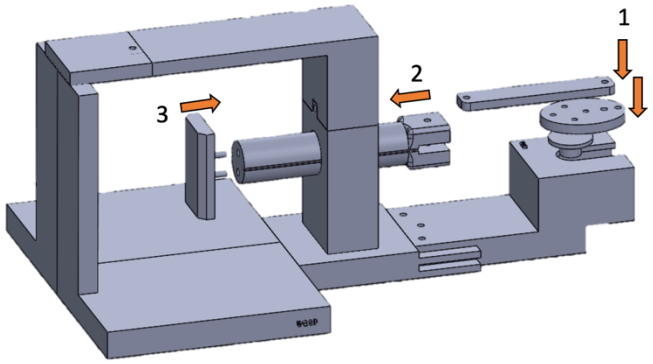
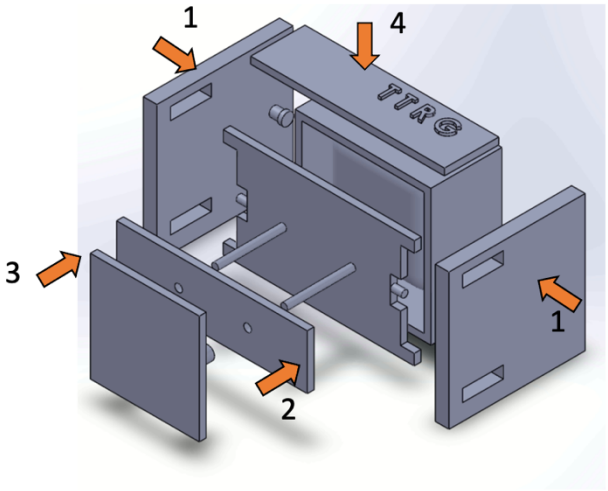
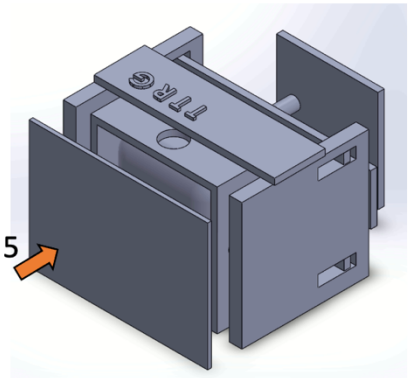


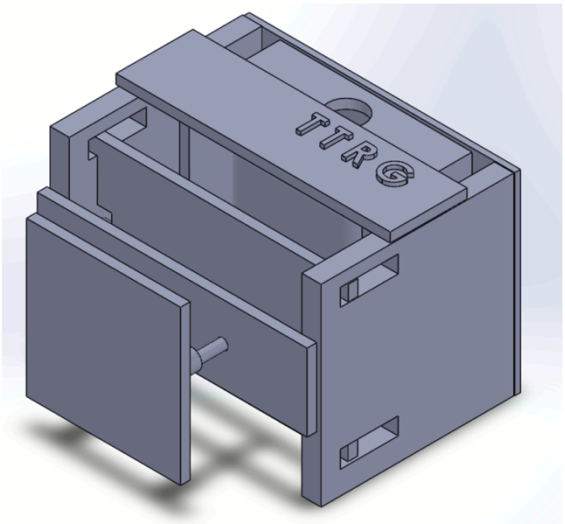
After assembled, bars of 10 mm, 20 mm, and 29 mm need to be used to fix the components. Please print and prepare bars at the steps: Step 1: 3 bars - 20 mm, Step 4: 2 bars - 10 mm, Step 5: 1 bar-29 mm, 1 bar-10 mm (*Do not use epoxy*)
Epoxy gluing needs to fix the components with the bars. Epoxy glue has been chosen due to high bond strength, non-magnetic, and water resistance.

- **Motion Phantom**



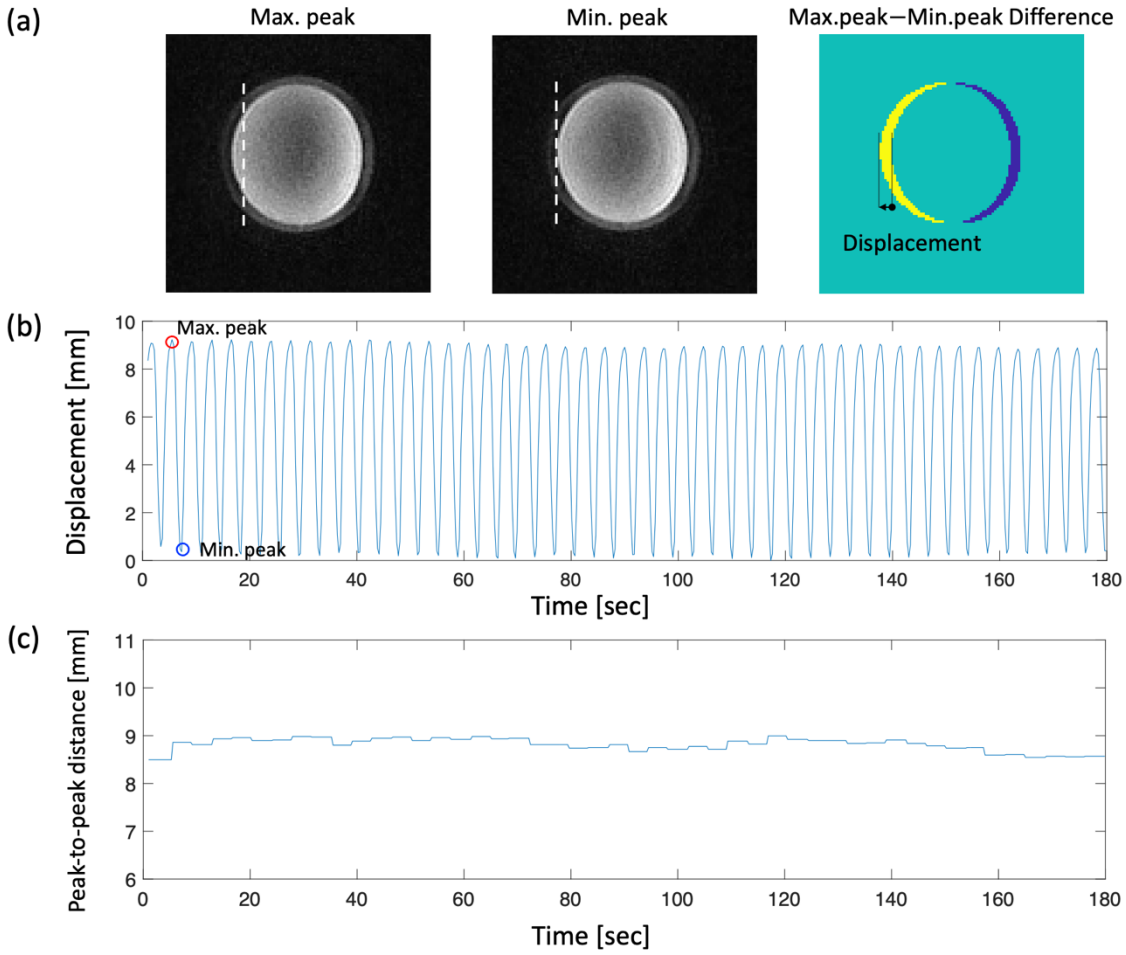


Completed phantom



Epoxy gluing needs to fix the components with the bars. Epoxy glue has been chosen due to high bond strength, non-magnetic, and water resistance.

4. Testing results



Displacements of the phantom with 1.65 L volume of the BVM. MR magnitude images (a, left, center) are shown on the coronal plane and white dashed lines indicate the original position of the phantom. (b) The displacement profile shows consistent and stable motions for 3 mins. Red and blue circles mean the maximum and minimum peaks of the navigator positions, respectively, corresponding to the magnitude images on the top. (c) Distances between the peak-to-peak displacements for 3 mins are plotted to evaluate the consistency of movement.

Table 1. Averaged distance between the peak-to-peak displacements for 3 mins, according to the volume of the BVM at 16 breaths/min.

Volume of BVM (L) /Additional plastic thickness (mm)	Averaged Distance (mm)
1.75 L/10 mm	5.0±0.1
1.7/30 mm	7.0±0.1
1.65/35 mm	8.8±0.1

The motion simulator allows various respiratory rates in the range of 8-16 cycles per min, while averaged distances are similar and only dependent on volume of BVM.