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Biomechanical liver characterization through Magnetic Resonance Elastography

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Introduction

Magnetic Resonance Elastography (MRE) is a validated clinical tool to characterize liver tissues [1]. To do so, MRE measures **liver elasticity** by imaging the propagation of a shear wave (Fig 1) that is externally generated and propagates in the liver. Higher stiffness induce greater shear wave speed and hence longer wavelengths are obtained on stiffer (and thus pathological) liver tissues as compared to healthy liver.

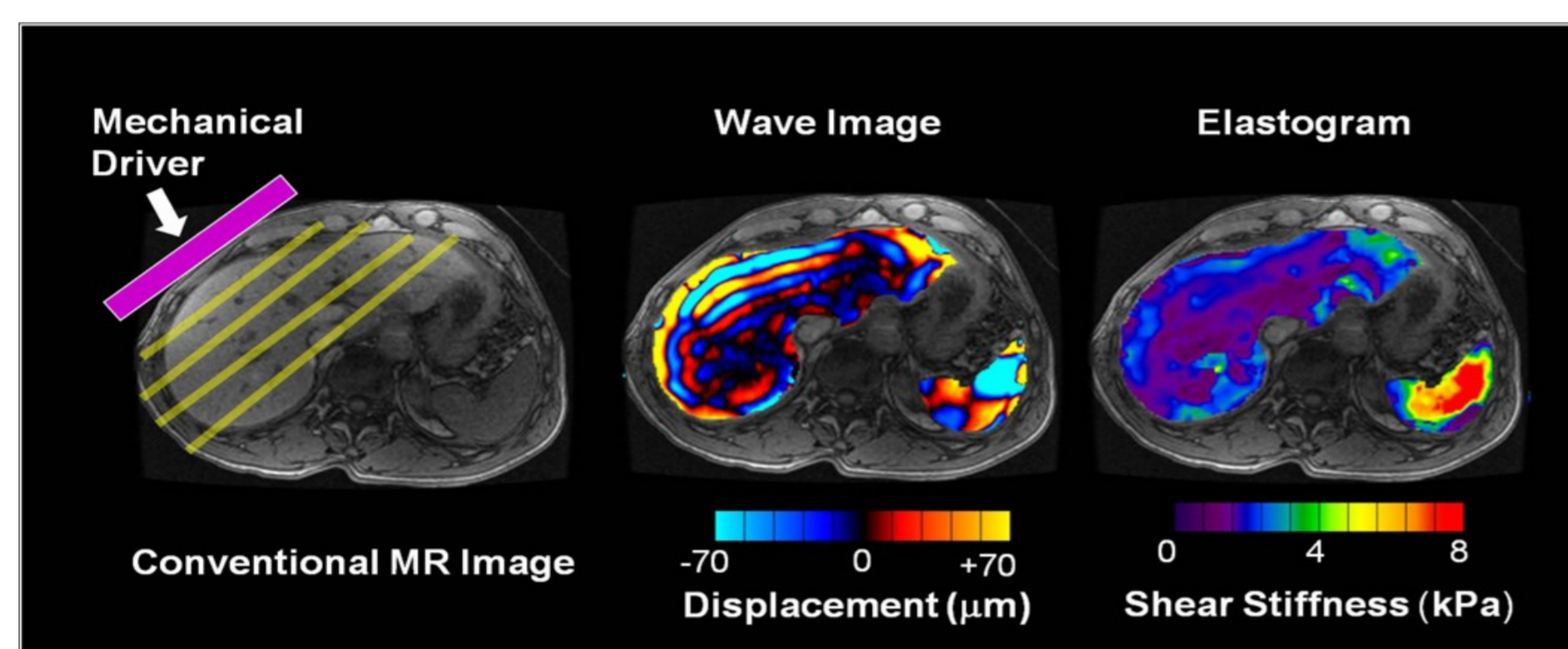


Fig 1 : MRE is performed in three steps. (a) A source of vibration is placed on the surface of the body to generate mechanical waves in the tissues of interest. (b) A special MRE pulse sequence with synchronized motion encoding gradients is used to image the micron-level cyclic displacements caused by the propagating waves. The wavelength of the shear waves is longer in stiffer tissues and shorter in softer tissues. (c) The wave images are then automatically processed with an "inversion algorithm" to create quantitative images depicting the stiffness of tissue. (For these illustrations, the portions of the wave image and elastogram corresponding to liver and spleen have been superimposed on a conventional MR image.)⁸

Imaging requires the use of a particular phase contrast MRI sequence whose main characteristics is the application of Motion Encoding Gradients (MEG) placed between slice excitation and signal measurement thus increasing the echo time (Fig 2). Longer MEGs increase the phase encoding at the expense of lower signal magnitude so finding the right equilibrium is necessary.

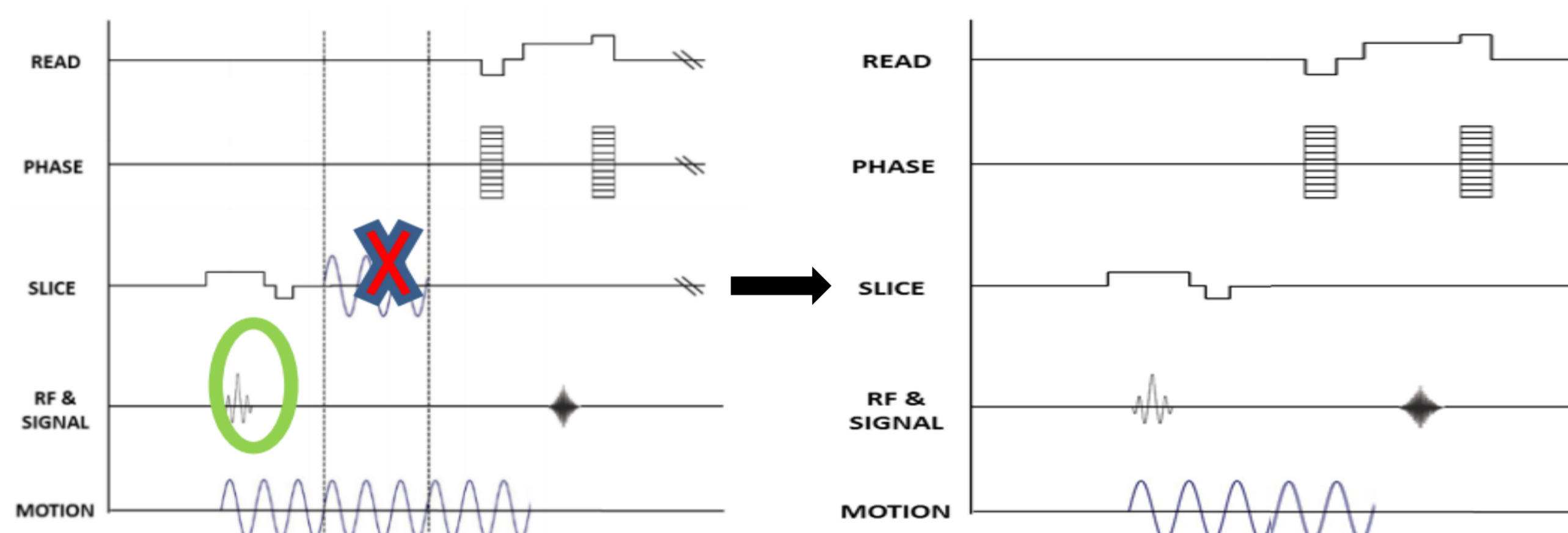


Fig 2 : Standard MRE acquisition

Fig 3 : Optimal Control MRE acquisition

In the case of **hemochromatosis**, due to high iron content in the liver, **T2* values are shortened causing a rapid loss of signal** and the subsequent **failure of MRE** to produce conclusive results [2] (Fig 4, Fig 5).

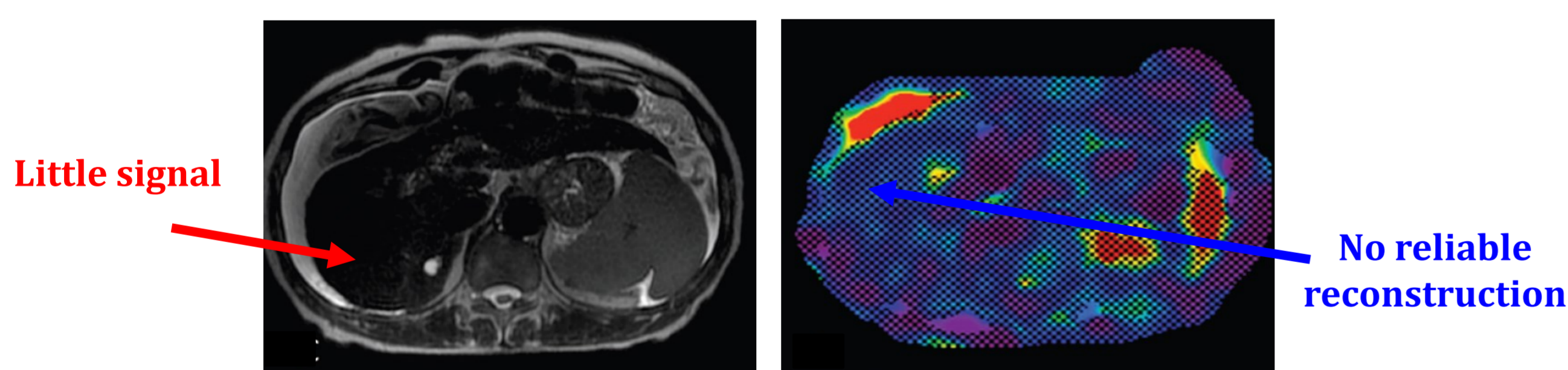


Fig 4 : Magnitude (left)/reconstructed (right) images – MRE failure due to extended echo times and shortening of T2*

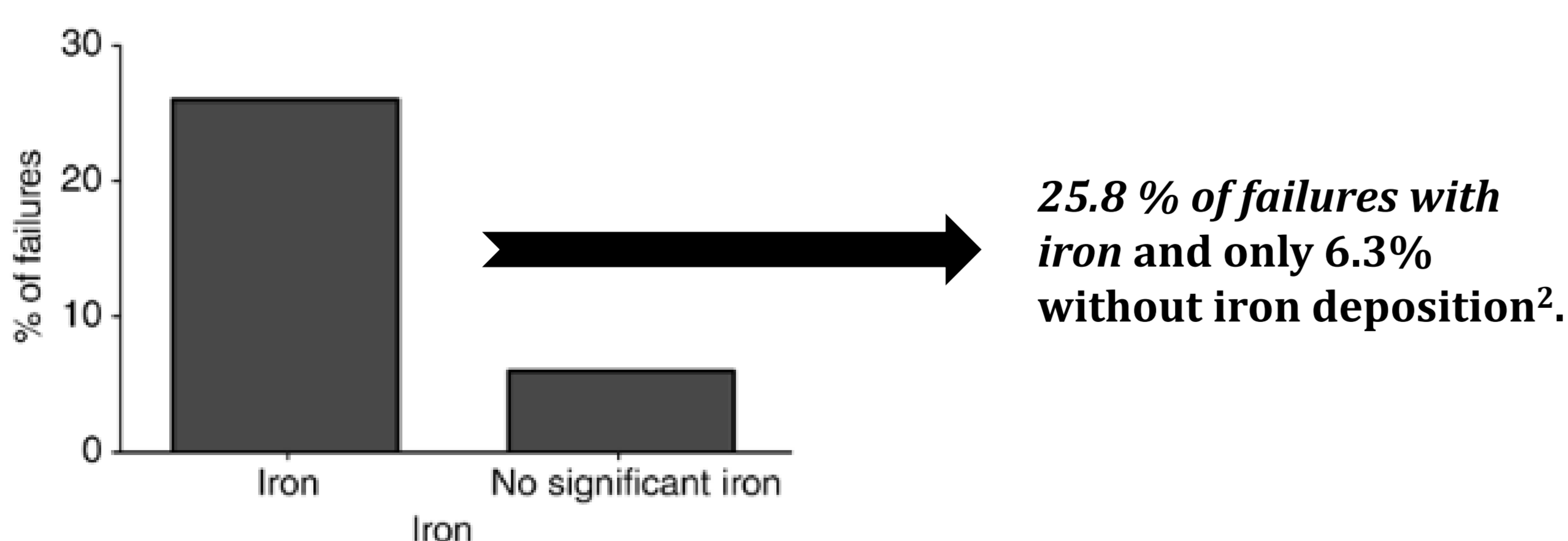


Fig 5 : Graph show distributions of the failure rate of MR elastography⁷.

Optimal Control MRE is a novel concept proposed by our team. Its principles resides in **designing a specific RF excitation pulse** which simultaneously achieves slice selection and motion encoding in slice direction (Fig 3)[3]. The optimization procedure enables maximization of phase encoding and signal magnitude with respect to a given T2 value. Moreover, recent works have shown its compatibility with ultrashort echo time strategies [4].

Optimal control MRE is therefore an interesting candidate for **liver elasticity measurement in the context of short T2 occurring during hemochromatosis**. However, this new technique has yet to be **applied and to demonstrate its superiority in an in vivo context**.

Methods

To demonstrate our technique in vivo, we need to :

- **Design a device to acquire MRE images for mouse models** on a preclinical MRI. This device includes an **RF coil for signal measurement at the proton Larmor frequency** at 7T (300 MHz) on a preclinical MRI and a **mechanical actuation system to induce shear waves in the liver**.

A **literature review** was done to design a dedicated RF coil integrating a mechanical driver. Chin et al. proposed a simulation method for the conception of birdcage coil [6], which we followed to obtain the desired resonance frequency.

- The first **experimental demonstration** will be carried out on a preclinical MRI first on a phantom (in vitro), then on a standard mice for instrumental development and finally on a *Hfe*^{-/-} mouse model which develops hemochromatosis. **Comparison with standard MRE sequences** will be made to **evaluate the performance of Optimal Control** based strategies.
- Finally, a proof on concept will also be sought on a clinical MRI on healthy volunteers.

Results

Initial measurement on a VNA have validated the design of the first prototype built (Fig 6) with a resulting resonance frequency of 305 MHz, (Fig 7) (close to the targeted proton Larmor frequency at 7T).

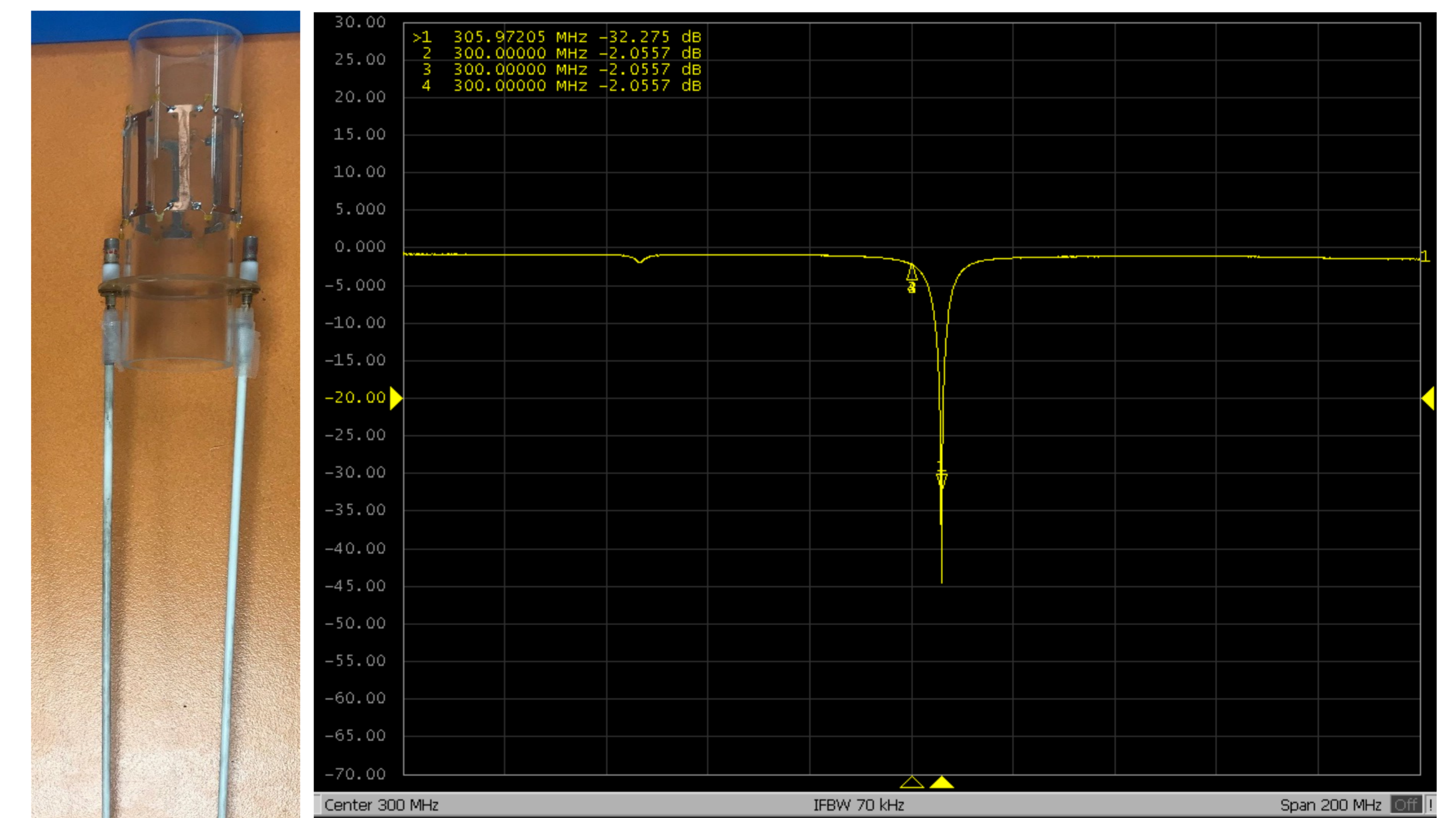


Fig 6 : A designed Birdcage coil prototype

Fig 7 : VNA Test to verify the resonance frequency

Work in under way concerning the design and integration of the mechanical actuation system and the RF coil. Figure 8 displays the general concept.

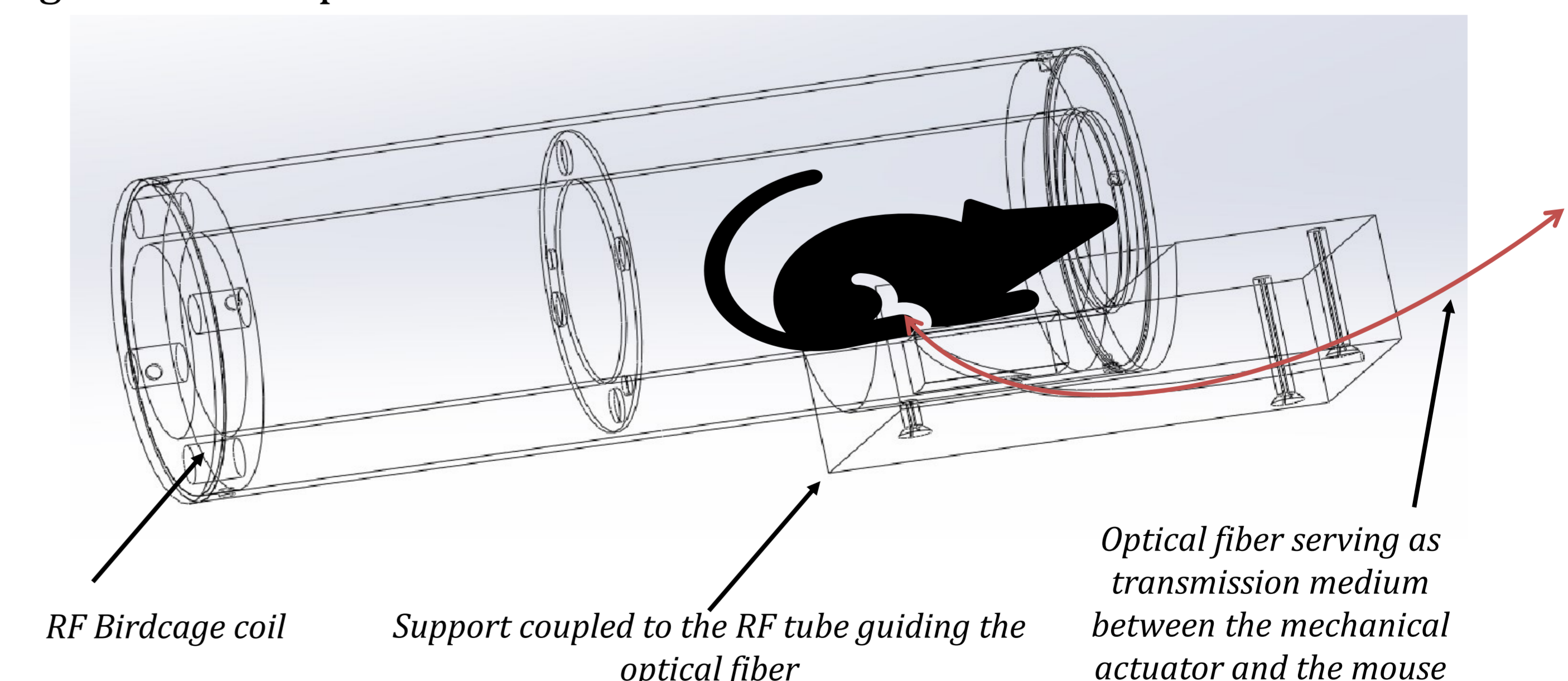


Fig 8 : RF Birdcage coil/mechanical actuation system

Discussion and Conclusion

The prototype coil (Fig 6) did not include MR-compatible electronic components so a final version of the birdcage coil is under construction and will be assembled with mechanical actuation system.

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