Sample Testing and Preparation for 21.1T MRI Applications

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Introduction

The 21.1T magnet at the National High Magnetic Field Laboratory (NHMFL) is the world's strongest Magnetic Resonance Imaging (MRI) magnet, enabling high-resolution MRI of biological and physical samples. The main scope of this project is to learn and implement various techniques involved in MRI sample preparation. These techniques can be categorized into four major areas: sample preparation, storage in cryogenic environments, bench evaluation with RF coils, and testing samples in the magnet. Each process requires mastering different techniques and skills to achieve optimal performance for high-resolution MRI images.

I participated in three different studies that focused on MRI samples:

- **Study 1:** Focused on preparing high-concentration samples of potassium chloride (KCl) to evaluate an existing 39K MRI Radio Frequency (RF) coil.
- **Study 2:** Involved designing and constructing a cryogenic dipper to store MRI samples at 77K.
- **Study 3:** Concentrated on evaluating the phantoms in the 21.1T magnet to obtain high-quality images.

This paper outlines the techniques and skills I learned through these studies, aiming to improve protocols and enhance image quality in MRI for advanced biomedical research.

Methods

The different techniques I learned to support the three studies are classified individually under sample preparation, storage, bench evaluation, and magnet testing.

Preparation

Recently, there has been growing interest in studying the naturally abundant (93.26%) isotope ^{39}**K** *in vivo* to evaluate intracellular functions and further investigate the concentration of potassium ions in the mice ear canal. Although ^{39}K has short relaxation times and low sensitivity, meaningful results can be obtained at ultra-high fields, as stated in [1]. To conduct a feasibility study for mice experiments, I prepared samples with different KCl concentrations to evaluate their performance both on the bench and later in the magnet, focusing on observing the T2 relaxation times.

Results: Different concentrations of KCl were prepared on a hot plate using a magnetic stirrer, as shown in Table 1. Each mixture was transferred into a 15ml test tube for bench evaluation, shown in Figure 1.

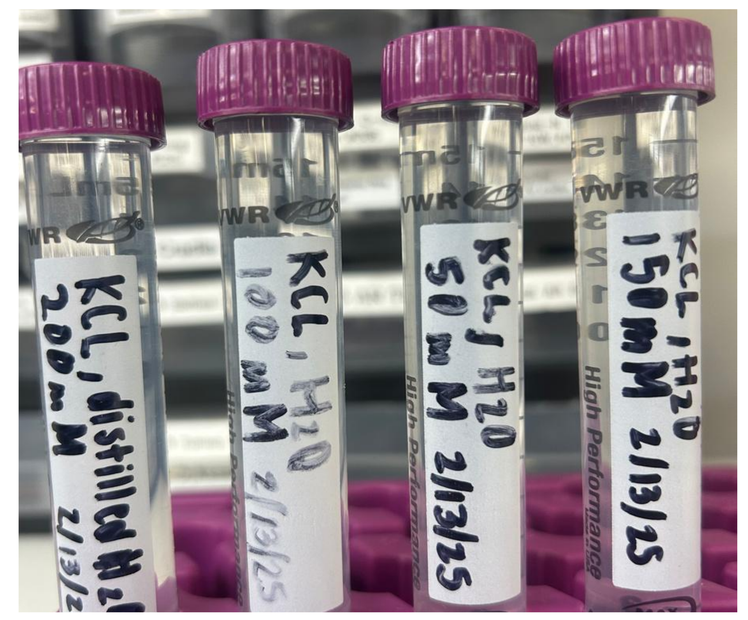


Figure 1: KCL Samples: 50mM, 100mM, 150mM, 200mM

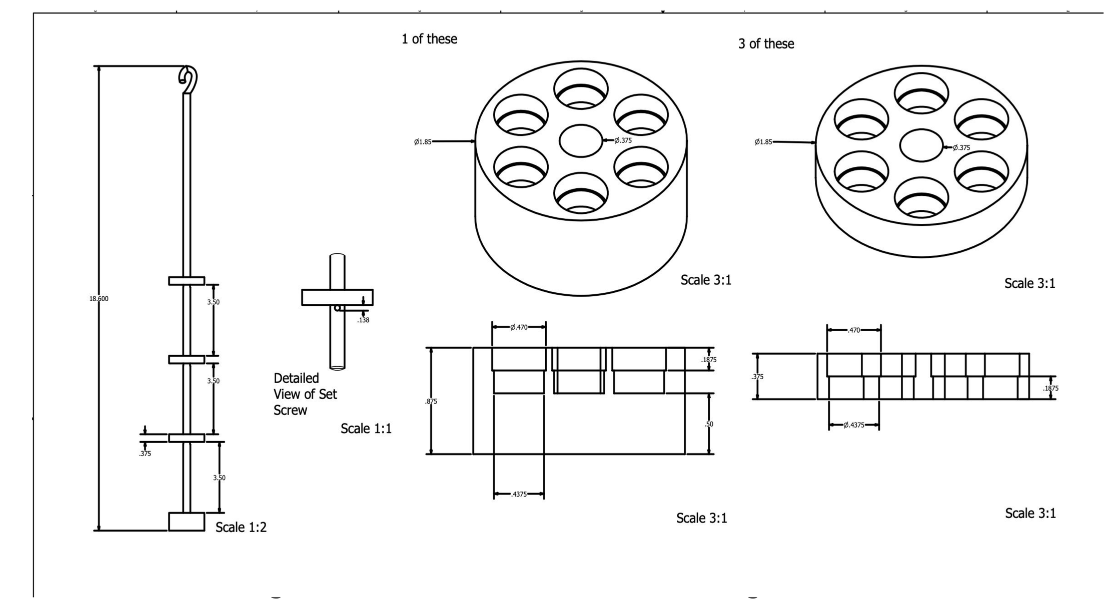
KCl Concentration (mM)	Mass of KCL (g)	Volume of H20 (mL)
50	0.373	100
100	0.746	100
150	1.118	100
200	1.491	100

Table 1 : phantom measurements

Storage

To support the bioluminescence study on triple quantum sodium signal changes in HepG2 liver cancer cells, a cryogenic dipper was designed to store samples at 77K. This device can store 24 samples of 2 mL cell each in a 25L Cryo-Diffusion tank filled with liquid nitrogen, ensuring optimum storage conditions. The samples are stored at cryogenic temperatures to maintain cell integrity. To complete this study, I learned three different techniques: Computer-Aided Design (CAD) for modeling the parts, 3D printing for prototyping the parts, and Computer Numeric Control (CNC) for precise machining of the parts.

Results: As shown in Figure 2a, I modeled the part using Autodesk Inventor Professional (Autodesk Inc, CA), and as shown in Figure 2b, I used Photon Mono X (Shenzhen Anycubic Technology Co., Ltd.) and Form 3+ (Formlabs, Inc., MA) to 3D print and prototype the parts. Figure 2c shows the parts printed using Anycubic standard translucent green resin and the Form 3 durable resin. As shown in Figure 2d, CNC machining was used to fabricate the aluminum components of the cryogenic dipper. The machining process involved using a lathe, mill, and saw to precisely machine the necessary parts. The machined cryogenic dipper along with the 25L tank is shown in Figure 2e. Additional spare Aluminum pieces were machined to test shrinkage at cryogenic temperatures. The shrinkage observed was negligible.



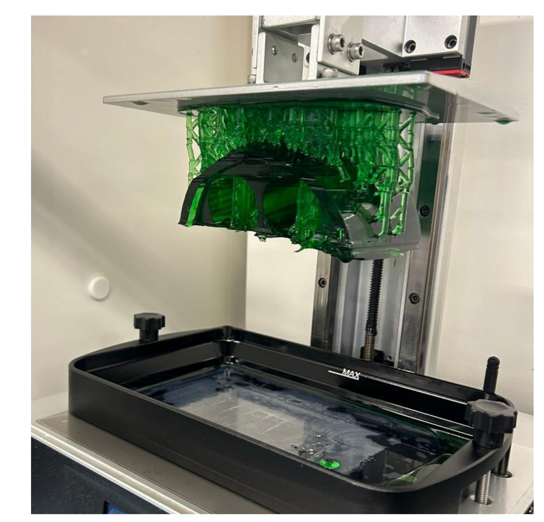


Figure 2b: Anycubic Photon Mono X

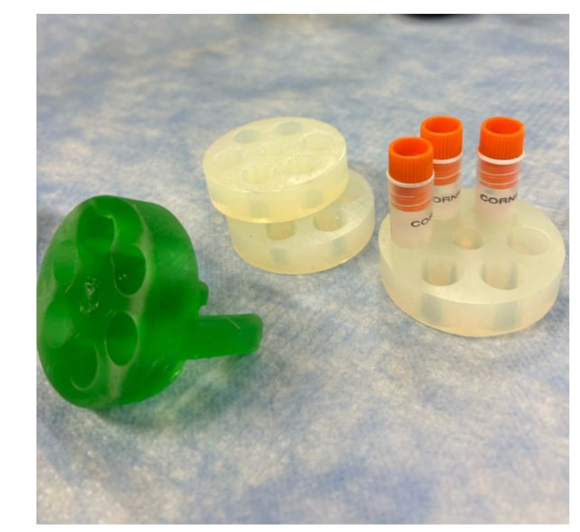


Figure 2c: 3D Printed Cryovial Plates

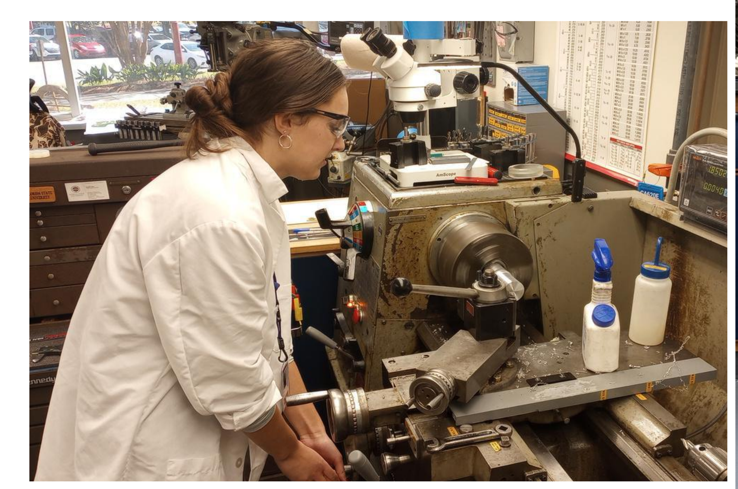


Figure 2d: Lathe used to machine a diameter of 1.85" on each plate

Figure 2e: Cryogenic Dipper in liquid nitrogen tank

Bench Evaluation

For study 1, I had to evaluate the coil performance of the 39K RF coil using the different concentration of KCl samples I had prepared. The coil efficiency is measured by its ability to tune to the resonant frequency, the tuning range across varying load conditions and the Quality factor at -3dB bandwidth. I utilized CMT808U (Copper Mountain Technologies, Indiana) Vector Network Analyzer (VNA) to make the above measurements.

Results: The Alderman-Grant 39K coil [2], tunes at 39K resonant frequency of 41.7 MHz as shown in Fig 3a. The Q(-3dB) was 96 when unloaded and 89.4 when loaded with 200 mM KCl. Since it operates at low frequency, the tuning range remains within +/-0.5 MHz across all load conditions. This suggests that magnet testing is crucial for evaluating the KCl samples, as the bench results showed minimal variation.

Magnet Evaluation

The measurements in the 21.1T magnet were supported by the Bruker Avance Neo Console hardware and Paravision PV360 3.5 software. To optimize the magnet's performance for imaging phosphocreatine phantoms, MRI scans were conducted to assess field homogeneity, strength, and stability. These evaluations produced precise imaging of ions under different load conditions.

Results: Figure 4a shows the phosphocreatine MRI scan obtained from a 15 mL phantom tube. I plan to conduct similar experiments in the future to evaluate the KCl samples in the magnet.

Figure 3a: Tuning of 39K coil @41.7 MHz

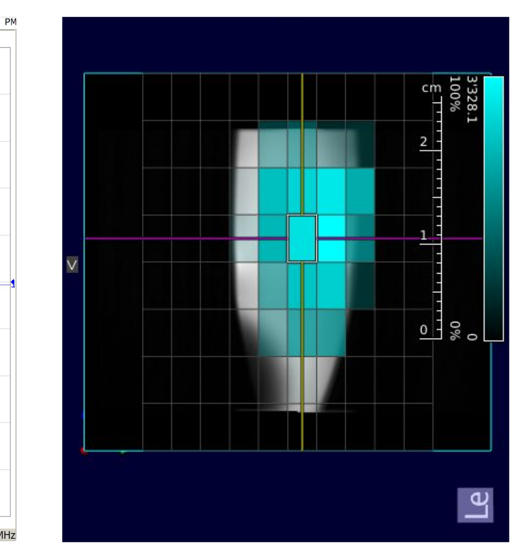


Figure 4a: Phosphocreatine MRI Scan

Acknowledgments

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References

[1] A. M. Nagel et al., "39K and23Na relaxation times and MRI of rat head at 21.1 T," NMR in Biomedicine, vol. 29, no. 6, pp. 759–766, Apr. 2016, doi: https://doi.org/10.1002/nbm.3528.

[2] C. E. Hayes, "The development of the birdcage resonator: a historical perspective," *NMR in Biomedicine*, vol. 22, no. 9, pp. 908–918, Nov. 2009, doi: https://doi.org/10.1002/nbm.1431.