# Development of a Non-Magnetic Support and Optimization of Magnetic Resonance Imaging Protocol for Wrist Examination

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## Abstract

*This study describes the development of a non-magnetic support for wrist magnetic resonance imaging (MRI) and the optimization of an advanced imaging protocol. By using non-magnetic materials and implementing techniques such as parallel imaging and advanced sequences such as SPACE, the goal is to improve both image quality and patient comfort. The results demonstrate that the use of the support and advanced technologies reduces the risk of artifacts and acquisition times, thus improving diagnostic efficiency. This idea arises from the need to optimize the normal technical procedures of a radiological examination through which to provide a global benefit that includes the patient, the radiologist and the quality of the images.*

## Introduction

Magnetic resonance imaging of the wrist is crucial for diagnosis complex pathologies. Requiring advanced acquisition protocols to ensure high spatial resolution and optimal image contrast. However, the standard protocol may have limitations in terms of patient comfort and image quality due to prolonged acquisition times and the risk of motion artifacts. This study aims to develop a non-magnetic support to improve wrist positioning and optimize an imaging protocol incorporating advanced technologies such as parallel imaging and the SPACE sequence to enhance image quality and reduce acquisition times.

## Materials and Methods

### Development of the Non-Magnetic Support

The non-magnetic support was designed to ensure the correct positioning of the wrist during MRI examination, improving both image quality and patient comfort. The support was made using fir wood and polylactic acid (PLA), materials selected for their properties:

- **Non-magnetic:** The absence of metal components avoids interference with the MRI magnetic field, ensuring disturbance-free acquisition.
- **Biocompatibility:** Wood and PLA are suitable for prolonged skin contact and can be easily sanitized.
- **Manufacturing flexibility:** The ease of processing wood and PLA allowed the creation of complex and adaptable shapes to fit the wrist morphology.

In this specific case, the non-magnetic support that we will illustrate was made from a manually carved fir wood beam and worked to create the lateral bases of the support with a purchase and processing cost of approximately €50; the cylindrical axes that form the bridge as well as the support surface were also made from fir wood with manual carvings and involved a purchase and processing cost of approximately €5-10; the joints made from polylactic acid for 3D printing were made using a Creality Ender 3 3D printer with production costs of approximately €10. In total, approximately €65-70 were spent on the creation of the support.

### Development process

The development process included several design and prototyping stages:

- **CAD Design and 3D Printing:** A 3D model of the support was created using open-source CAD software like Thinkercad, and prototypes were produced in PLA.
- **Prototype Evaluation:** Three main prototypes were developed and tested. Prototype 1 (Fig. 1) had stability and material workability issues. Prototype 2 (Fig. 2) had an unstable shape, while Prototype 3 (Fig. 3) was expensive and complex to manufacture. After multiple tests, the Final Prototype was created (Fig. 4).
- **Modular Assembly:** The final design of the

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modular stand consists of two angled triangular bases, four arched structures and two cylindrical axes that act as a connecting bridge for the two triangular bases, as well as a support surface for the limb under examination and two guides below the triangular bases that connect to the MRI table, allowing stability and ease of positioning.

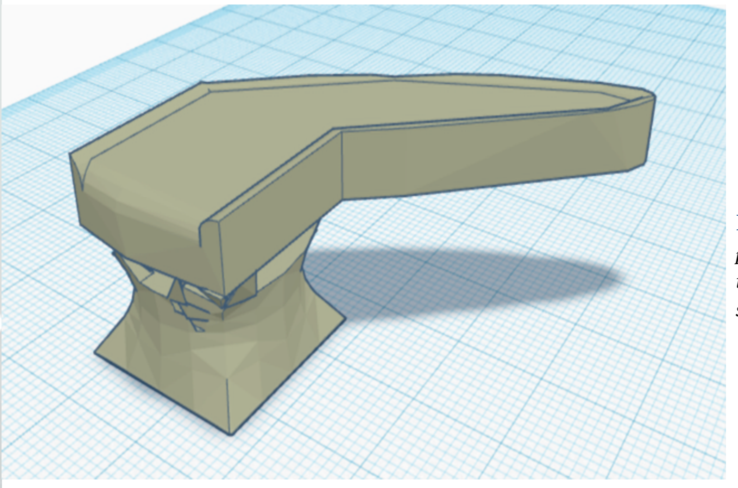

**Figure 1.** *Prototype 1 of the support. This presented problems related to the realization, therefore to the processing of the materials, and to the design*

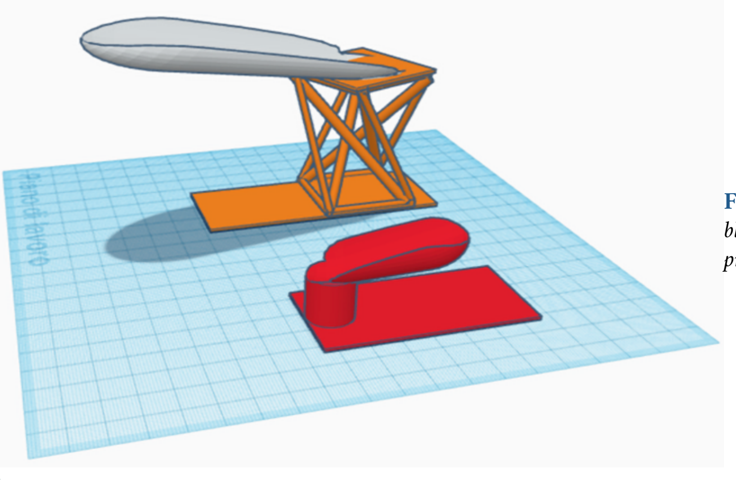

**Figure 2.** *Prototype 2. This had problems with shape stability and material processing and was therefore inefficient.*

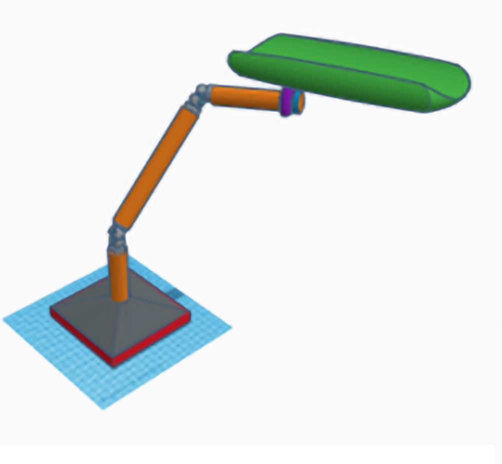

**Figure 3.** *Prototype 3. It presented problems related to the cost of materials and the difficulty of construction as well as dynamics of structural instability which led to its exclusion.*

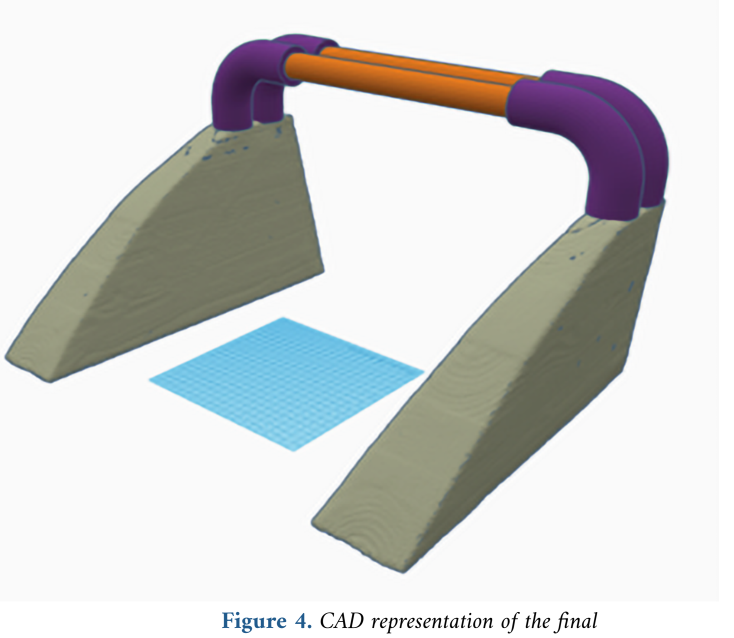

**Figure 4.** *CAD representation of the final*

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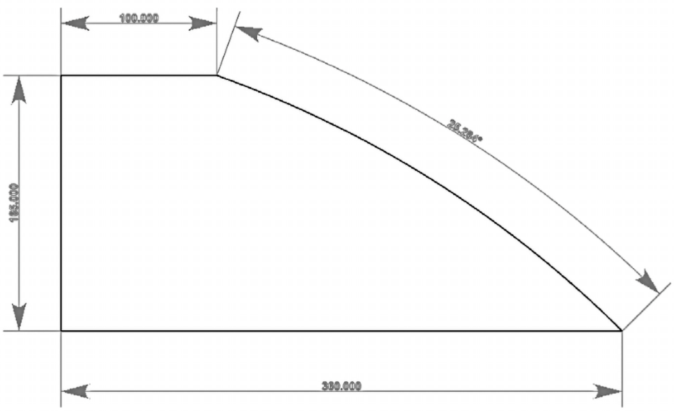
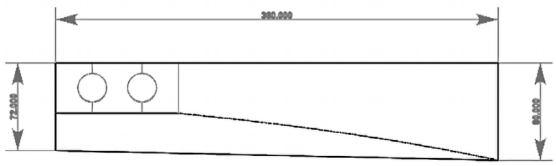
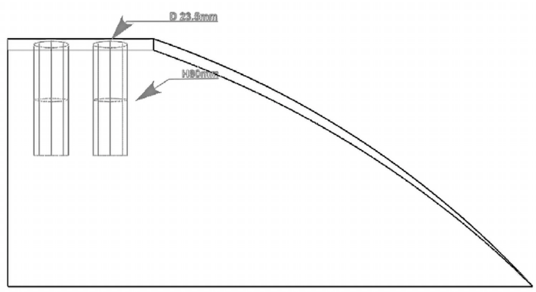
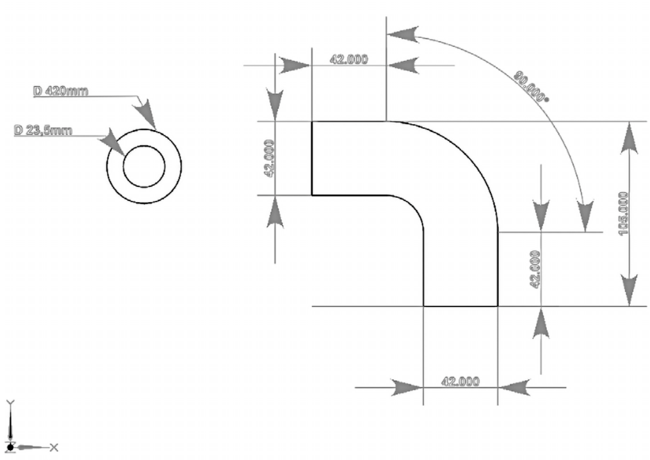
**Non-magnetic support specifications**

The measurements relating to the technical drawings of the support are given in millimeters.



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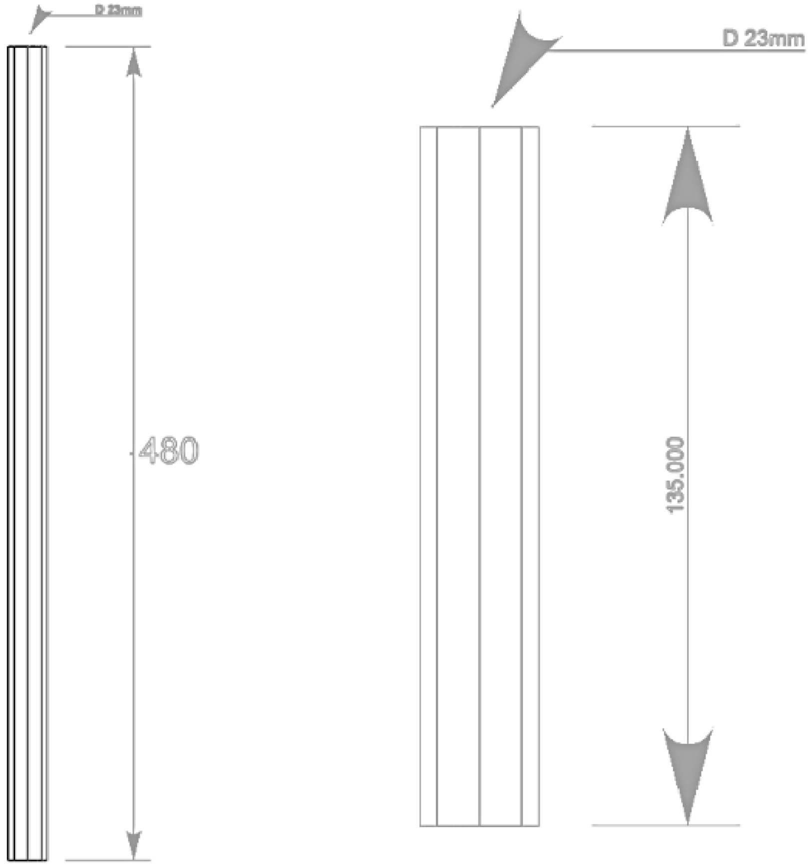
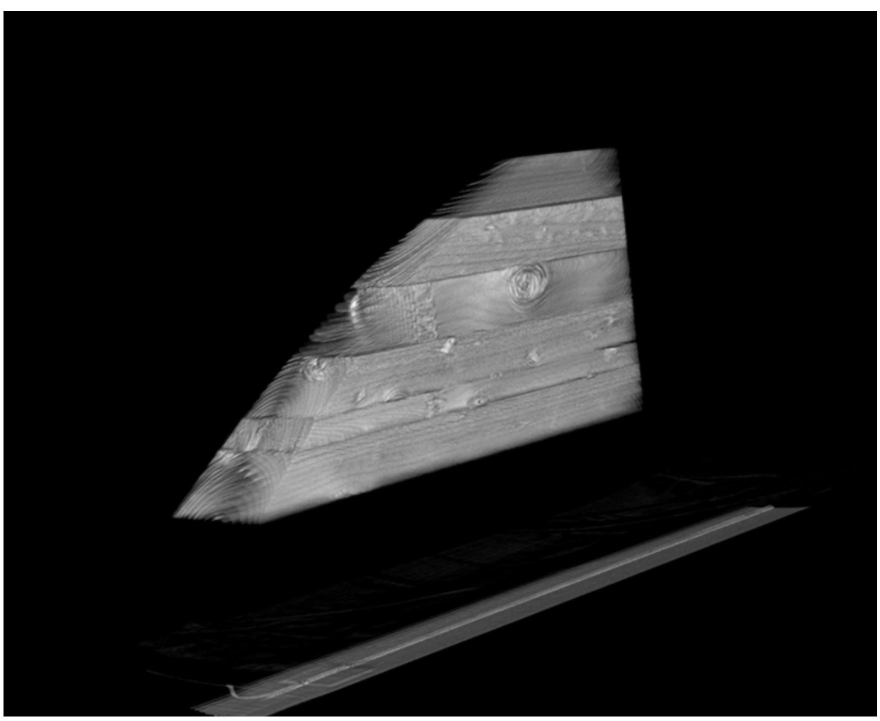



**Stability and Non-Magnetism Testing**

The support was subjected to mechanical and magnetic stability tests. CT scans (Fig. 8) were performed to confirm the absence of ferromagnetic components, verifying that the support does not interfere with the MRI magnetic field. Additionally, mechanical tests demonstrated that the support could maintain wrist stability throughout the examination duration.



**MRI Protocol Optimization**

The standard wrist imaging protocol considered is the hospital protocol used in the Trani PTO (Trani, BAT, Italy) on a Siemens Magneton Aera 1.5 T device and which involves the use of the following sequences: T1, T2, PD, STIR and GRE T2*, to ensure complete coverage of the anatomical structures. However, this approach resulted in an acquisition time of approximately 35-40 minutes, which is long for patient comfort and susceptible to motion artifacts.

**Optimized Protocols**

To improve the imaging protocol, the following were introduced:

- **SPACE Sequence (Sampling Perfection with Application optimized Contrasts using different flip-angle Evolutions):** This 3D TSE sequence provides high-resolution isotropic images that can be reformatted into various planes without quality loss. The SPACE sequence offers high resistance to susceptibility artifacts and chemical shift, making it ideal for imaging complex anatomical structures such as the wrist.
- **Parallel Imaging (GRAPPA):** Parallel imaging allows reduced scan times by acquiring data simultaneously using multichannel phased array coils. Specifically, the GRAPPA technique was used to decrease sampling along the phase encoding direction, significantly reducing acquisition time.
- **Phased Array Coils and 7-Channel Loop Coil:** The combination of an 18-channel flex coil with a 7-channel loop coil improved spatial resolution and signal-to-noise ratio (SNR) due to the extended coverage of the 18-channel coil and the focal capability of the loop coil.

**Acquisition Parameters**

With the optimized protocol, acquisition time was reduced to approximately 15 minutes, bringing the total examination time to around 25-30 minutes. Key parameters included:

- **TR and TE (Time of Repetition and Time of Echo):** Optimized to enhance tissue contrast.
- **Slice Thickness and Voxel Size:** Reduced slice thickness and isotropic voxels for improved resolution.
- **Phase Oversampling:** Reduced to limit aliasing artifacts

## Results

After outlining the standard protocol used for wrist MRI imaging and detailing the optimizations made to enhance image quality and reduce acquisition times, the following section presents the results related to the validation of the optimized protocol.

*Using the non-magnetic support and positioning*

The non-magnetic support is designed to be easy for radiology technicians to apply. For efficient use, the patient is placed in a supine position on the MRI table. The previously assembled support is then positioned around the patient, with the triangular bases placed under the arms and the limb being examined positioned on the cylindrical axes connecting the two bases. For greater stability, foam padding may be used if necessary. The "Body 18 channels" coil is positioned under the wrist being examined, resting on the cylindrical axes, acting as a support surface and receiving coil. After ensuring the correct position of the patient, a "Loop 7" coil is applied to the wrist being examined. For greater stability, a sandbag, supplied with the MRI, may be used to prevent movement or slipping of the wrist. In this way, through the use of the non-magnetic support, both the patient and the coils required for the examination are correctly positioned.

*Image Quality and Acquisition Time Comparison*

The adoption of the optimized protocol showed significant improvements in image quality:

- **Higher Resolution:** Images obtained with the SPACE sequence revealed anatomical details of wrist tendons and bones with greater resolution than the standard protocol.
- **Artifact Reduction:** The robustness of the SPACE sequence and the use of parallel imaging significantly reduced motion and susceptibility artifacts.
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*Evaluation of the Non-Magnetic Support*

The support has been shown to be effective in maintaining wrist stability, reducing the impact of patient micro-movements and thus contributing to improving image quality and reducing motion artifacts. In order to minimize patient motion artifacts, a sandbag can be applied to the patient's wrist, other types of possible motion artifacts are those from breathing that can be kept to a minimum through the use of saturation bands during sequence setup.

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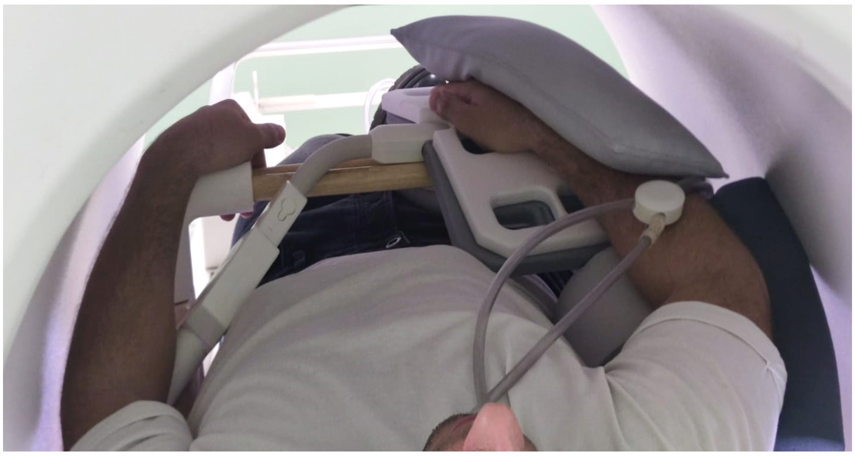
**Tables 1** *show the sequences and parameters used in the standard protocol and optimized protocol.*

| | STANDARD PROTOCOL | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sequence** | LOCALIZER TRA | ALIZER TRA+COR+S | T2 TSE FS SAG | PD TSE FS COR | T1 TSE COR | STIR COR | T1 TSE TRA | PD TSE FS TRA | 3D GRE VIBE TRA | DWI TRA |
| **Parameters** | | | | | | | | | | |
| TA (min) | | | 4,15 | 4,3 | 1,28 | 4,5 | 2,12 | 2,45 | 5,1 | 3,2 |
| Slice Group | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Slice/Slab | | | 20 | 12 | 12 | 12 | 20 | 20 | 25 | 12 |
| Disance Factor | | | 10% | 10% | 25% | 20% | 30% | 30% | 5% | 15% |
| Phase Encoding Direction | | | F >> H | H >> F | H >> F | H >> F | R >> L | A >> P | R >> L | R >> L |
| Phase Oversampling | | | 100% | 200% | 200% | 120% | 120% | 150% | 200% | 100% |
| FOV Read (mm) | | | 140 | 150 | 100 | 130 | 120 | 120 | 160 | 125 |
| FOV Phase (%) | | | 100% | 90% | 100% | 85% | 100% | 100% | 95% | 80% |
| PAT | | | off | off | off | off | off | off | off | off |
| Voxel size | | | 0.3 x 0.3 x 3.0 mm | 0.3 x 0.3 x 3.0 mm | 0.3 x 0.3 x 3.0 mm | 0.3 x 0.3 x 3.0 mm | 0.3 x 0.3 x 3.0 mm | 0.3 x 0.3 x 3.0 mm | 0.3 x 0.3 x 3.0 mm | 0.3 x 0.3 x 3.0 mm |
| Slice Thickness (mm) | | | 3 | 3 | 3 | 3 | 3 | 3 | 1,5 | 4 |
| TR (ms) | | | 3000 | 4500 | 526 | 5500 | 568 | 1570 | 8 | 7000 |
| TE (ms) | | | 70 | 30 | 23 | 35 | 14 | 28 | 2,5 | 80 |
| Averages | | | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 4 |
| Concatenations | | | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 |
| Saturation Region | | | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| Fat Suppression | | | FS | FS | None | STIR | None | FS | DIXON | None |

| | OPTIMIZED PROTOCOL | | | | | | |
|---|---|---|---|---|---|---|---|
| **Sequence** | LOCALIZER TRA | ALIZER TRA+COR+S | T1 TSE COR | PD TSE FS TRA | T2 TSE FS DIXON COR | T1 SPACE TRA FS | TOF 2D TRA |
| **Parameters** | | | | | | | |
| TA (min) | | | 5,04 | 4,06 | 4,14 | 5,03 | 3,52 |
| Slice Group | | | 1 | 1 | 1 | 1 | 1 |
| Slice/Slab | | | 20 | 35 | 20 | 88 | 48 |
| Disance Factor | | | 0% | 10% | 10% | 0% | -30% |
| Phase Encoding Direction | | | R >> L | R >> L | F >> H | A >> P | R >> L |
| Phase Oversampling | | | 100% | 70% | 70% | 100% | 20% |
| FOV Read (mm) | | | 250 | 180 | 230 | 203 | 260 |
| FOV Phase (%) | | | 78.1% | 100% | 100% | 71.9% | 68.8% |
| PAT | | | off | 2 | 2 | 2 | off |
| Voxel size | | | 0.4 x 0.4 x 3.0 mm | 0.4 x 0.4 x 3.0 mm | 0.4 x 0.4 x 3.0 mm | 0.4 x 0.4 x 0.8 mm | 0.8 x 0.8 x 3.5 mm |
| Slice Thickness (mm) | | | 3 | 3 | 3 | 0,8 | 3,5 |
| TR (ms) | | | 605 | 4710 | 4000 | 550 | 481 |
| TE (ms) | | | 13 | 36 | 78 | 24 | 7 |
| Averages | | | 1 | 1 | 1 | 1 | 1 |
| Concatenations | | | 2 | 1 | 1 | 1 | 48 |
| Saturation Region | | | 0 | 2 | 0 | 3 | 2 |
| Fat Suppression | | | None | FS | DIXON | FS | None |

**Figure 9** *shows a comparison of images from the T1 TSE sequence.*



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## Discussion

The introduction of the non-magnetic support and optimized imaging protocol significantly improved both the quality of MRI wrist images and examination efficiency. The SPACE sequence, with its ability to produce isotropic images, allowed for reduced acquisition time without sacrificing diagnostic quality. Parallel imaging, combined with phased array and loop coils, further enhanced resolution.

The non-magnetic support, designed to improve wrist positioning stability, helped to reduce motion artifacts and improve patient comfort. Together, these elements made MRI wrist examination faster, more comfortable, and more diagnostically effective.

5. Conclusions

The development of a non-magnetic support and the optimization of the MRI protocol for wrist examination improved image quality and diagnostic efficiency, while also reducing patient discomfort. This approach represents a significant advancement in radiological practice for wrist diagnostics and could be adopted as a new reference standard.

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