A phantom-based method to measure MRI distortion from pedicle screws for spine radiotherapy planning

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Introduction

- **MRI is an essential tool for visualizing radiation treatment planning structures** for spine metastasis treatment planning.[1,2]
- Spinal fixation may be necessary for some spine cancer patients which involves placing metal implants (pedicle screws) to decompress and stabilize the spinal column.[3-5]
- **Metal implants cause MRI image artifacts** (geometric distortions/signal loss/pile up).[1,6-9]
- There are **many MRI metal artifact reduction (MAR) techniques**:
  - Conventional sequence parameters changes[8,9]
  - View Angle Tilting (VAT): additional slice-select gradient applied with readout gradient, reducing in-plane pixel shifts[6-10]
  - Siemens WARP
  - Slice Encode for Metal Artifact Correction (SEMAC): additional phase encoding in the slice direction to correct for between-slice signal distortion[6,9,11]

Objective: Develop **a phantom-based method** to **measure the geometric accuracy** of MRI images near pedicle screws and compare different metal artifact reduction strategies.

Phantom Design

- Holes were drilled into an acrylic block.
- 84 Teflon ball bearings (diameter = 2.54 mm) were placed into drill holes and used as internal reference markers. Drill holes constricted at specific heights to position reference markers vertically in phantom.
- 2 pedicle screws were placed in larger drill holes.
- Phantom was placed on a platform with registration rods and in a water-filled container.
- Figure 1 shows phantom design schematic and Figure 2 shows image of phantom.

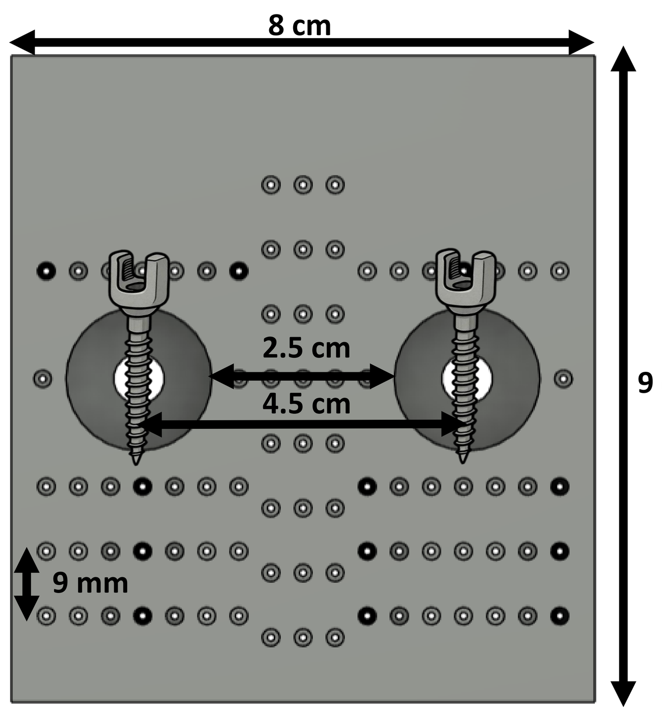

Figure 1: Phantom schematic. Screw images were generated using ChatGPT.

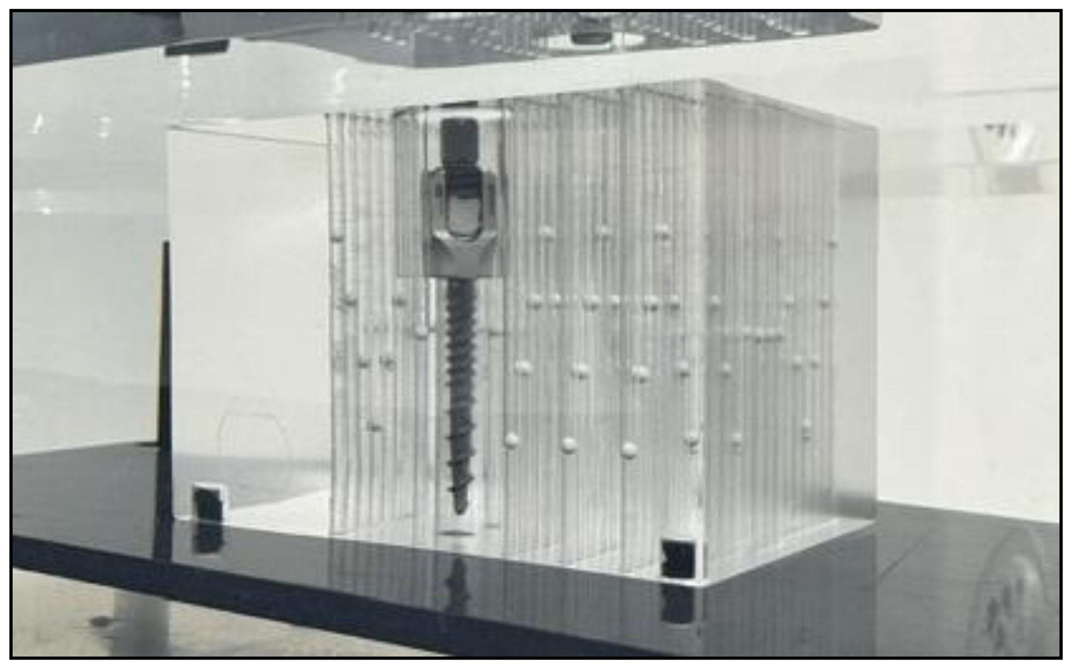

Figure 2: Phantom in CT scanner with pedicle screws showing reference marker positions.

Data Collection

- **MRI data (Siemens Sola Fit 1.5T)**: T2-weighted 2D turbo spin echo (TR/TE = 3570-15960/76-87 ms, resolution = 0.977 x 0.977 x 3 mm^3) with/without screws were collected.
  - MAR techniques sampled:
    - **Pixel bandwidths**: 201, 300, 399, 501, 592 Hz and **VAT**: 0, 20, 40, 60, 80, 100 %
    - **SEMAC**: 6, 18 and **pixel bandwidths:** 190, 399 Hz
    - **SEMAC:** 12 and **pixel bandwidths**: 190, 399, 592, 814 Hz
- MRI frequency encoding direction was aligned right-left in axial slices.
- Figure 3 displays example MRI images collected.

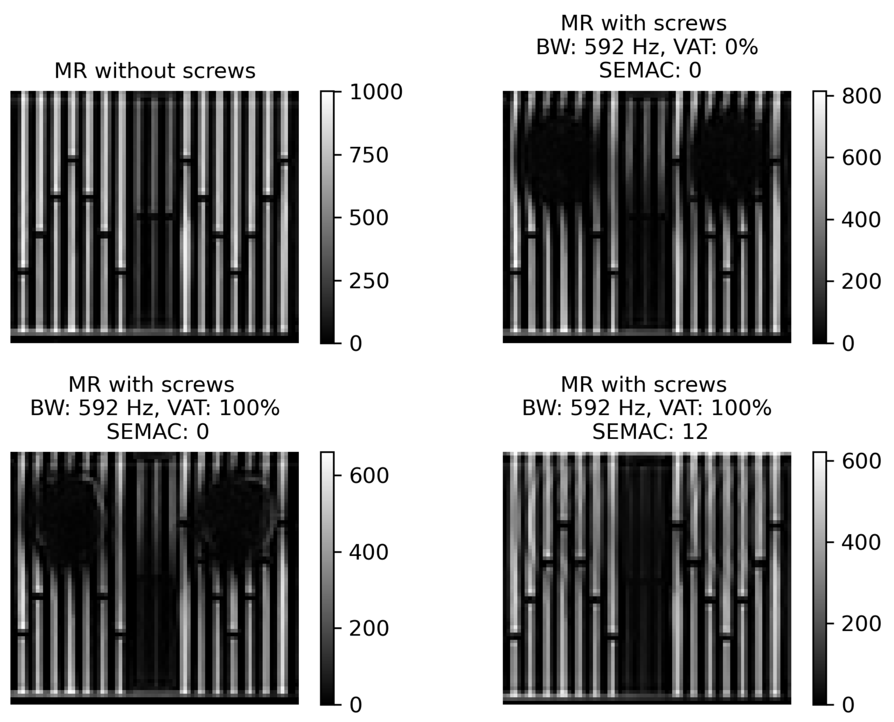

Figure 3: Example MRI images collected in a single matching slice.

Data Analysis

- The MRI image with no screws was manually registered to one of the MRI images with screws using Aria.
- An automated analysis pipeline was used to detect reference marker positions, with manual correction as needed. Figure 4 shows example automated and manually corrected reference marker positions.
- Distortion was quantified by calculating the Euclidian distance between reference marker position for the MRI with/without screws.

Outcome Metrics

1. **Percentage of reference markers whose positions were automatically located** across all MRI scans.
2. **Total distortion** (calculated by summing distortion across all reference markers for each MRI image).
3. **Reference marker distortion** (graph of reference marker distortion vs. distance from pedicle screw was created for a single reference marker).

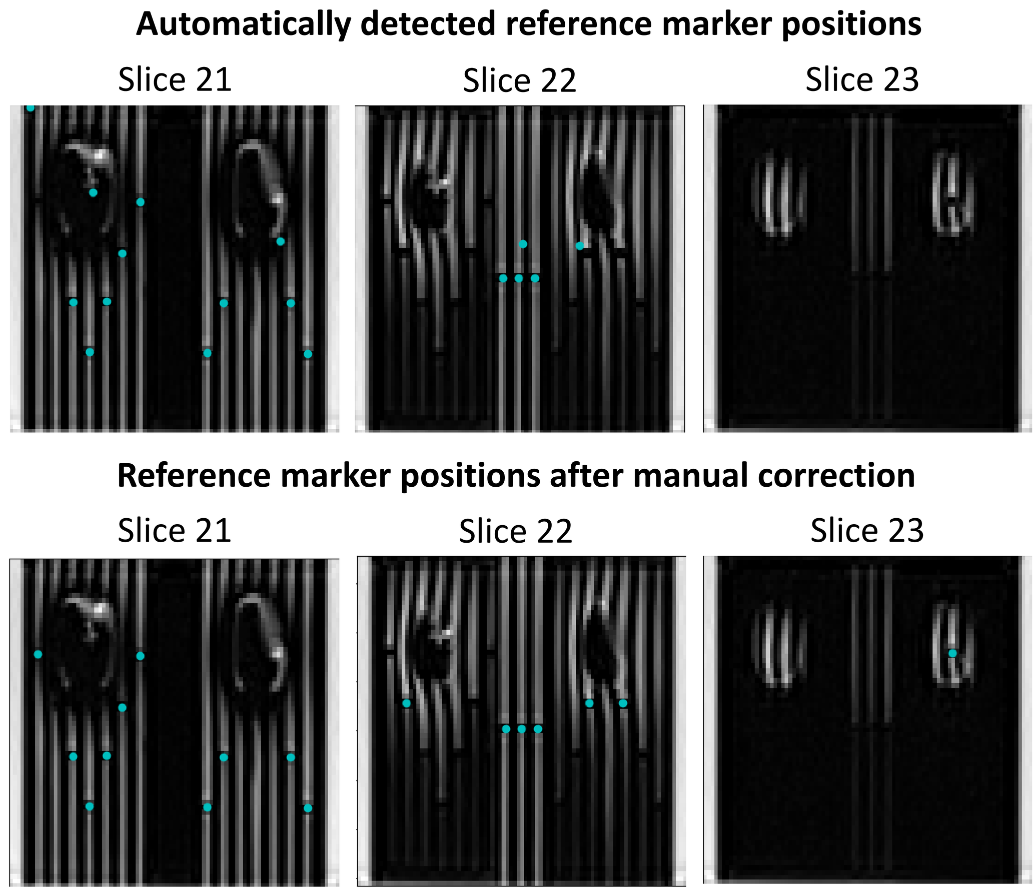

Figure 4: Example automated and manually corrected reference marker positions for MRI image with screws (pixel bandwidth: 592 Hz, and VAT: 100%).

Results

- **Percentage of reference markers whose positions were automatically located:** 76% on average (range = 50 – 89 %)
- **Total distortion** (Figure 5 & 6)
  - → Decreases with pixel bandwidth, as expected.
  - → No large difference as VAT % increases for larger pixel bandwidths (300 – 592 Hz).
  - → Decreases with WARP when pixel bandwidth increases.
  - → Decreases with SEMAC as pixel bandwidth increases.
  - → No considerable differences for images with SEMAC values of 6, 12, 18.
- **Reference marker distortion** (Figure 7)
  - → Decreases with distance from screw, as expected.
  - → Lowest distortion was seen when SEMAC was used, which is expected as it accounts for between-slice distortion.

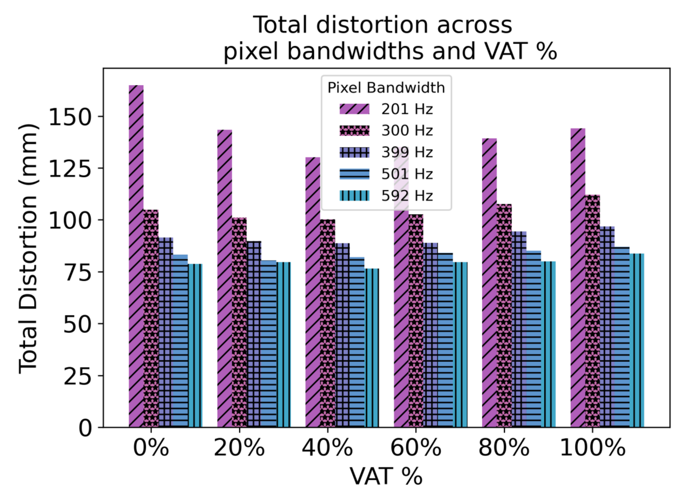

Figure 5: Total distortion across all reference markers for 30 MRI images sampling pixel bandwidths and VAT %.

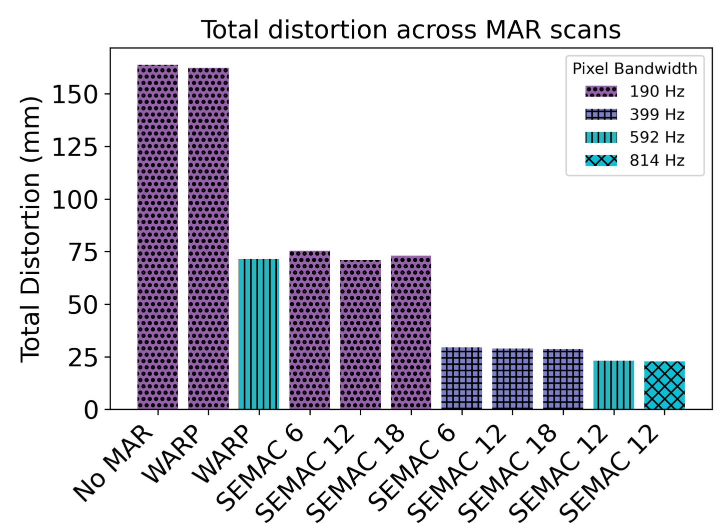

Figure 6: Total distortion across all reference markers for 11 MRI images with various metal artifact reduction strategies.

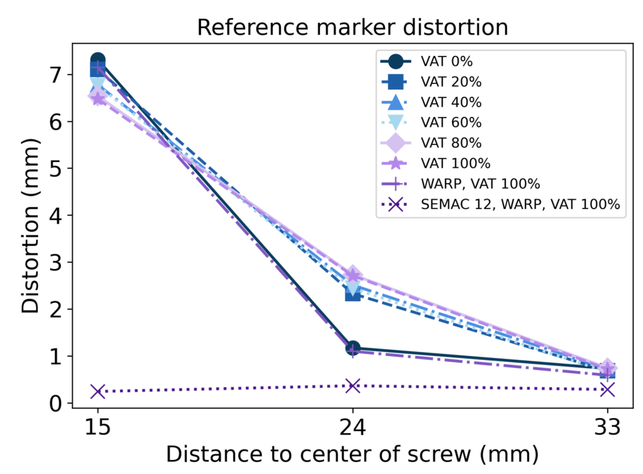

Figure 7: Reference marker distortion across 3 slices for various MAR strategies (pixel bandwidth = 592 Hz)

Conclusions

- A phantom and analysis technique to measure MRI geometric distortion near pedicle screws was developed, allowing for MAR strategies to be assessed and compared.

Limitations

- Distortion was difficult to assess when there was significant VAT blurring.
- Manual correction was done with knowledge of scan MAR technique.

Future Work

- Assess reproducibility of phantom geometric accuracy measurements by performing a scan-rescan study.
- Implement MAR techniques in vivo.

References

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