# MRI-based spine models for patient specific surgical planning

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INTRODUCTION: Scoliosis is an abnormal spine curvature mainly affecting children, progressing rapidly as they grow. If conservative treatment fails, surgery can prevent progression and improve spinal alignment. Implanting screws in a deformed spine can be challenging, risking spinal cord and nerve root injury, causing neurological issues. To address this, surgical planning tools can create patient specific guides. CT scans used to generate 3D models for surgical planning come with a high ionising radiation dose which is problematic for children, as it increases risk of radiation induced cancer, and it is not a clinical standard in the UK. Improvements in Magnetic Resonance (MR) imaging allow better bone-tissue delineation, with no radiation risk. It is safe for clinical pre-operative investigation and performed routinely in scoliosis surgery. This study aims to validate MR generated spine models compared with CT generated models.

METHODS: Porcine spine specimens (n=5) were acquired and imaged using a Somatom go.Sim CT scanner (Siemens) and a 3T Magnetom Prisma MR scanner (Siemens) using a T1 VIBE sequence (0.6mm$^3$ voxel size, TR=7.7ms, TE=4ms). Each acquired spine specimen has approximately 5 vertebrae. Each individual vertebrae were segmented (Simpleware Scan IP, Synopsys) using semiautomated threshold techniques from the two imaging modalities. 3D models were exported, and the MR and CT models were registered together using an iterative closest point technique (Artec Studio 13). The CT model was used as the reference mesh and the distance from reference mesh analysis was performed (Meshlab) calculating the overall mean difference and root mean square (RMS) deviation. 2D imaged based measurements were performed by a single operator on both MR and CT images (Simpleware Scan IP, Synopsys). 2D measurements were defined from literature [1,2] with a focus on key measurements used for defining pedicle screw positioning. These included anterior vertebral body height (AVBH), inferior vertebral body length (IVBL), inferior vertebral body width (IVBW), pedicle axis length (PAL), pedicle height (PH) and pedicle width (PW). A Bland-Altman analysis was performed to compare the two different modalities for each measurement (MATLAB, Mathworks).

RESULTS: The mean difference and RMS deviation between MR derived bone models compared with gold standard CT models is seen in Table 1. The difference between 2D image-based measurements calculated from CT and MRI is seen in Table 2.

DISCUSSION: The overall difference (Table 1) between MR derived bone models against gold standard CT models is less than a single voxel of the MRI (0.6mm$^3$). This shows that 3D models generated from MRI are an accurate alternative to CT. For the 2D image-based measurements a larger root mean squared (RMS) error and wider 95% levels of agreement were seen for the measurements relating to pedicle screw positioning. This potentially could be related to the challenge of performing these measurements on both modalities. Further work is needed to quantify inter-operator and intra-operator error for these measurements. Overall mean difference between measurements is around 1 mm which has been suggested to be an acceptable error for measurements[1] relating to positioning of pedicle screws. Future work will look to add clinical MR imaging (1.5T) as an additional modality to compare against. With the aim to advise on which MR sequence is most suited for incorporating into future surgical planning software.

SIGNIFICANCE/CLINICAL RELEVANCE: (1-2 sentences): Implanting screws in a deformed spine can be challenging and the high ionising radiation associated with CT imaging means 3D surgical planning may not be suitable for children with scoliosis. This preliminary investigation into using MRI as an alternative 3D imaging technique has shown that it has similar accuracy, but care is needed for certain 2D image-based measurements.

REFERENCES: [1]Morbee et al. 2021, European Journal of Radiology, doi:10.1016/j.ejrad.2021.109999 [2]Morita et al. Surg Radiol Anat doi:10.1007/s00276-021-02707-8

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Table 1: Mean difference and RMS difference between CT (reference mesh) and MR derived vertebra models.

| | Specimen 1 | | Specimen 2 | | Specimen 3 | | Specimen 4 | | Specimen 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Vertebrae** | **Mean (mm)** | **RMS (mm)** | **Mean (mm)** | **RMS (mm)** | **Mean (mm)** | **RMS (mm)** | **Mean (mm)** | **RMS (mm)** | **Mean (mm)** | **RMS (mm)** |
| **T16** | -0.44 | 0.59 | | | | | | | | |
| **L1** | -0.16 | 0.41 | | | -0.55 | 0.66 | | | | |
| **L2** | -0.23 | 0.44 | -0.46 | 0.63 | -0.53 | 0.63 | | | -0.43 | 0.61 |
| **L3** | -0.17 | 0.46 | -0.4 | 0.6 | -0.53 | 0.63 | -0.51 | 0.61 | -0.35 | 0.51 |
| **L4** | -0.46 | 0.61 | -0.39 | 0.6 | -0.48 | 0.58 | -0.37 | 0.56 | -0.29 | 0.48 |
| **L5** | | | -0.3 | 0.5 | -0.52 | 0.65 | 0.43 | 0.59 | -0.25 | 0.48 |
| **L6** | | | -0.35 | 0.54 | | | -0.4 | 0.67 | -0.33 | 0.53 |
| **Overall** | -0.29 | 0.5 | -0.38 | 0.57 | -0.52 | 0.63 | -0.21 | 0.61 | -0.33 | 0.52 |

Table 2: 2D image-based measurement differences calculated from Bland Altman analysis.

| Measurement | RMS error (mm) | Mean Difference (mm) | 95% limits of agreement (mm) |
|---|---|---|---|
| **Anterior Vertebral Body Height (AVBH)** | 0.7 | -0.5 | -1.8 to 0.8 |
| **Inferior Vertebral Body Length (IVBL)** | 0.8 | -0.9 | -2.4 to 3.0 |
| **Inferior Vertebral Body Width (IVBW)** | 0.6 | -1.3 | -2.6 to 2.6 |
| **Pedicle Width (PW)** | 0.8 | -0.1 | -1.8 to 3.4 |
| **Pedicle Axis Length (PAL)** | 2.3 | -0.4 | -5.0 to 9.2 |
| **Pedicle Height (PH)** | 1.3 | -1.2 | -4.1 to 6.0 |