Morphological Errors of Three-Dimensional Bone Models of the Distal Femur and Proximal Tibia Obtained Using Magnetic Resonance Imaging and Computed Tomography with Different Slice Thicknesses

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INTRODUCTION

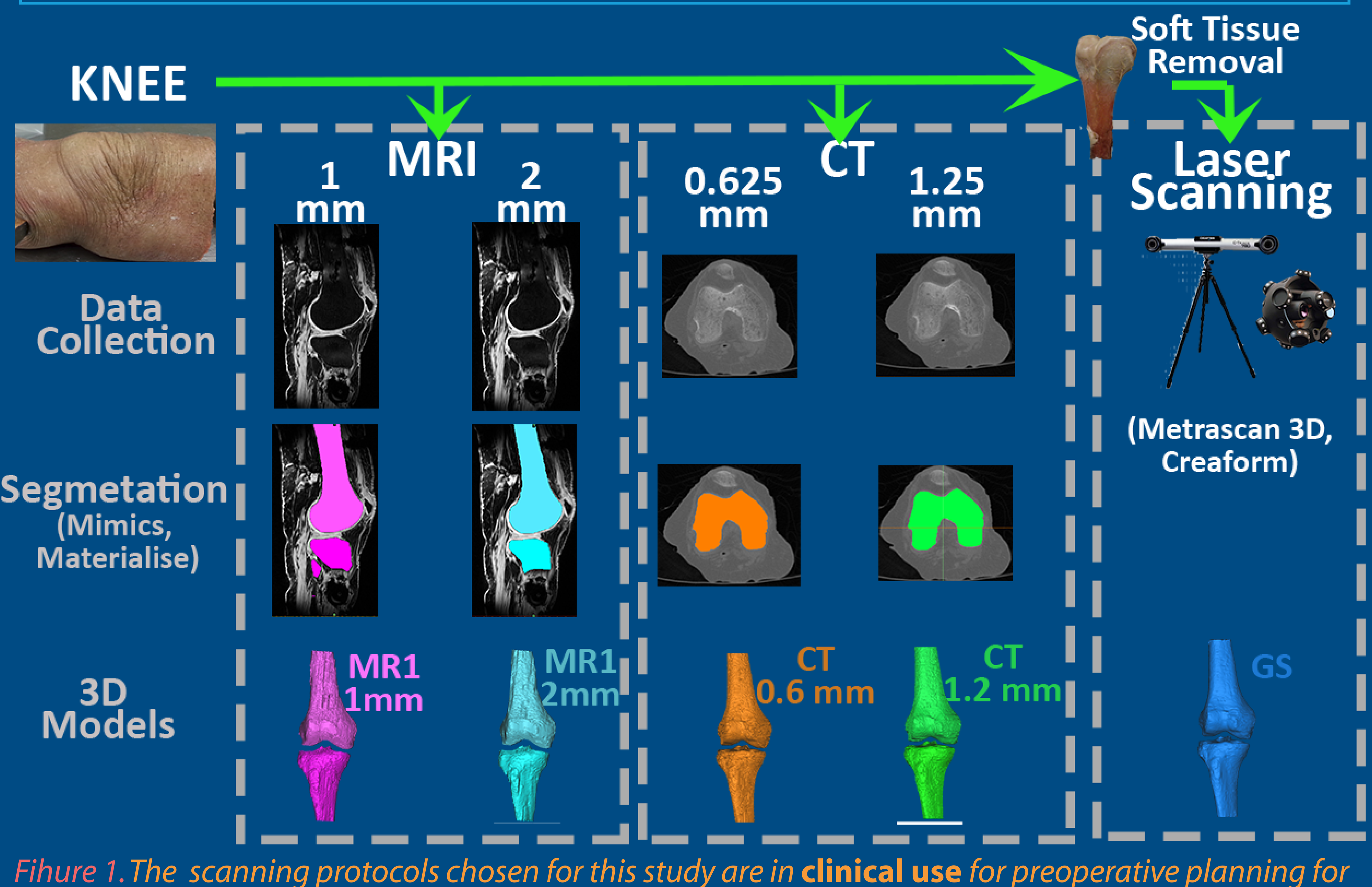
Several studies have demonstrated that three-dimensional (3D) bone models of the distal femur and proximal tibia generated with either magnetic resonance imaging (MRI) or computed tomography (CT) have morphological errors when compared to 3D bone models obtained with a laser scanner or to measurements on the dissected bone. MRI imaging protocols in clinical use are typically based on either a 1 or 2 mm slice thickness, with the 2 mm slice thickness being often preferred to the 1 mm because of the shorter scanning time. Similarly, CT imaging protocols in clinical use are based on either a 0.625 mm or 1.25 mm slice thickness, with 1.25 mm slice thickness being often preferred to the 0.625 mm for the lower radiation dose. However, no previous study known to the authors has investigated how an increase in the slice thickness of MRI and CT scans affects the morphological errors of 3D bone models generated with MRI and CT and has investigated both human distal femur and proximal tibia in the same study.

AIMS: ***1) Quantify whether MRI or CT generates bone model with the lowest morphological error compared to a gold standard bone model obtained with a high-accuracy 3D laser scanner and 2) quantify whether the increase in slice thickness increases the error in the 3D bone models.***

METHODS

The distal femur and proximal tibia of **three knees** were MRI-scanned using a 1 mm and 2 mm slice thickness protocol and CT-scanned using a 0.625 mm and 1.25 mm slice thickness protocol. Next, each knee specimen was dissected, disarticulated, and the femur and tibia were soaked in 6% sodium hypochlorate solution for up to 12 hours to remove cartilage, and finally scanned with an high accuracy laser scanner to generate a Gold Standard Model (GS) (Figure 1).

The morphological errors of the MRI and CT bone models were determined through a ***direct comparison with the GS model*** by calculating the ***deviations (i.e. 3D distance)*** between the surface of the MRI/CT bone models and the surface of the GS model after the bone models were registered using the ***iterative closest point algorithm*** (Geomagic, 3D Systems). For each knee, the overall deviation from the GS was reported in terms of root mean square deviation (RMSD) and average deviation (AD).



Fihure 1. The scanning protocols chosen for this study are in ***clinical use*** *for preoperative planning for patient-specific instrumentation (MRI) and robotic-surgery (CT) in total knee arthroplasty.*
MRI Scanning Protocol: *3D spoiled gradient echo sequence and sagittal oblique slices, with TR=17s, TE=4s, flip angle =12°, no slice gap/overlap, pixel size=0.94mm×0.94 mm, with 3T MRI scanner (Siemens, MAGNETOM® Trio) and knee coil.* ***CT Scanning Protocol****: clinical 32-slice CT scanner (GE LightSpeed), 120 kVp, smart mA, pixel size = 0.39 mmx 0.39 mm.*

RESULTS

AIM 1

The bone models generated with CT-scanning are more accurate than the bone models generated with MRI scanning because 7 out of the 8 error quantities computed for each of the imaging modalities are smaller for the CT models than the MRI models (Table 1, Figure 1).

Based on the AD errors, the MRI bone models are systematically **smaller** than the GS, while the CT bone models are systematically **larger** . However, this last result may be caused in part by the corrosive effect of sodium hypocholorate which may have shrunk the surface of the laser-scanned bone surface.

AIM 2

For the CT, the morphological errors of the bone models are not greatly affected by an increase in slice thickness, even if the smaller slice thickness CT scan still generates bone models with lower morphological errors because 2 out of the 4 error quantities computed for each of the two slice thicknesses are smaller for the 0.625 mm than the 1.25 mm while the other 2 are the same.

For the MRI, the morphological errors of the bone models are higher when a thicker slice thickness is used. Indeed, 4 out of the 4 error quantities computed for each of the two slice thicknesses are smaller for the 1 mm than the 2 mm slice thickness.

	Femur		Tibia	
	RMSD (mm)	AD (mm)	RMSD (mm)	AD (mm)
MRI - 1mm	0.5 ± 0.1	-0.3 ± 0.1	0.6 ± 0.0	-0.1 ± 0.1
MRI - 2 mm	0.7 ± 0.0	-0.5 ± 0.1	0.8 ± 0.1	-0.4 ± 0.1
CT - 0.625mm	0.5 ± 0.0	0.1 ± 0.1	0.5 ± 0.0	0.2 ± 0.0
CT - 1.25 mm	0.5 ± 0.0	0.2 ± 0.1	0.6 ± 0.1	0.2 ± 0.1

Table 1. Deviations of the MRI and CT femur and tibia models from the GS models expressed as the average across the three specimens of the root mean square deviation (RMSD) and the absolute deviation (AD) (Mean ± SD). Positive values of the AD indicate that the MRI/CT bone model islarger than GS, while negative values of the AD indicate that the MRI/CT bone model is smaller than GS.

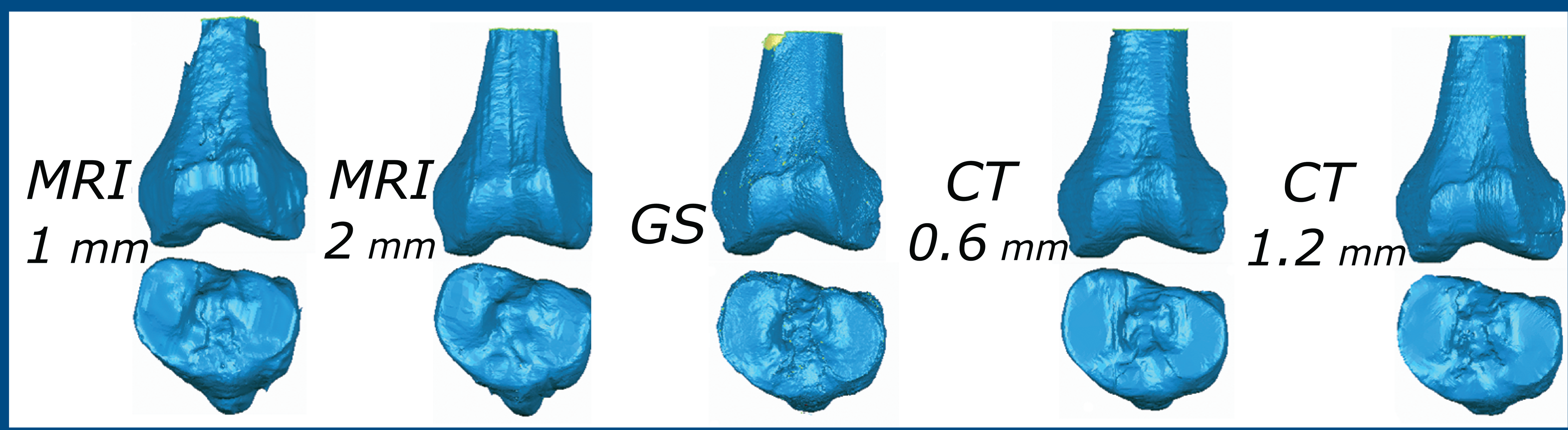


Figure 2. Bone models of the distal femur and proximal tibia obtained with MRI, CT, and laser scanning (GS) for an example specimen (left knee).

DISCUSSION and CONCLUSION

Researchers and clinicians using MRI and CT scans to generate bone models need to understand the consequences of using bone models with morphological errors and of using bone models generated using a bigger slice thickness. These consequences depend on the specific application of interest. It may be that a 0.5 mm error may not significantly affect the results of a finite element model, but it may significantly affect the outcome of a total knee arthroplasty performed with a surgical robot which relies on a planning performed with a bone model.

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