FlexTrac: CT-Compatible Knee Stabilization Device with Modular Traction Control

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Background

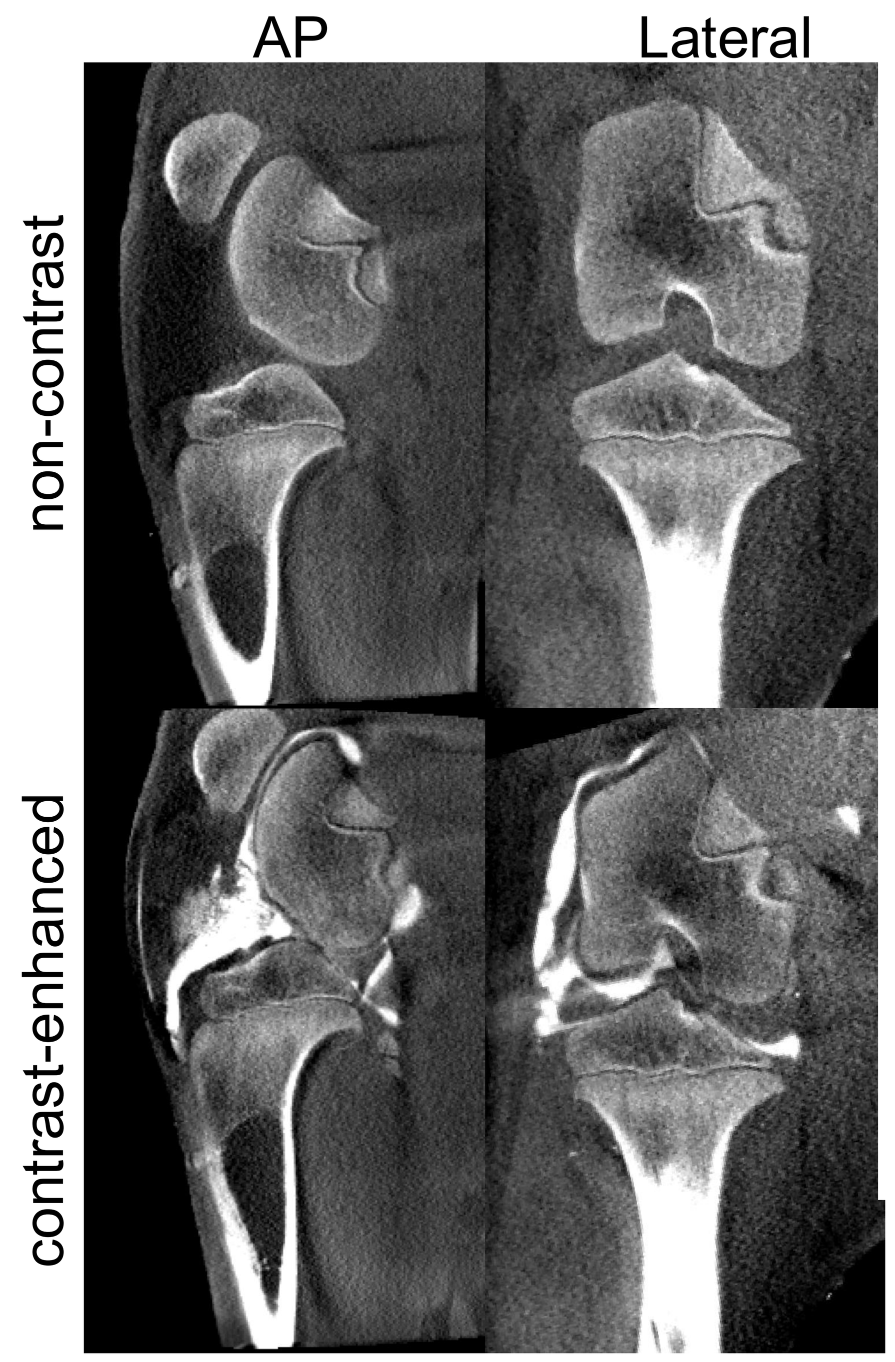
- Osteoarthritis (OA) is a degenerative joint disease in the knee that causes cartilage breakdown, stiffness, and pain
- **Clinical Motivation:** Standard diagnosis uses radiography and MRI to detect late-stage OA through joint space narrowing and irreversible cartilage loss. No modality currently detects early structural changes, when intervention may be most effective
- **How:** Dynamic CT arthrography measures iodine contrast diffusivity in the tibiofemoral joint space, offering a novel biomarker for early OA. This requires the knee to be stabilized in flexion while axial traction is applied to the tibia during scans. Current clinical setups are inconsistent and not adaptable across patients.
- **Project Objective:** FlexTrac is a CT-compatible stabilization device with modular traction control, improving imaging reliability and reproducibility

Methods

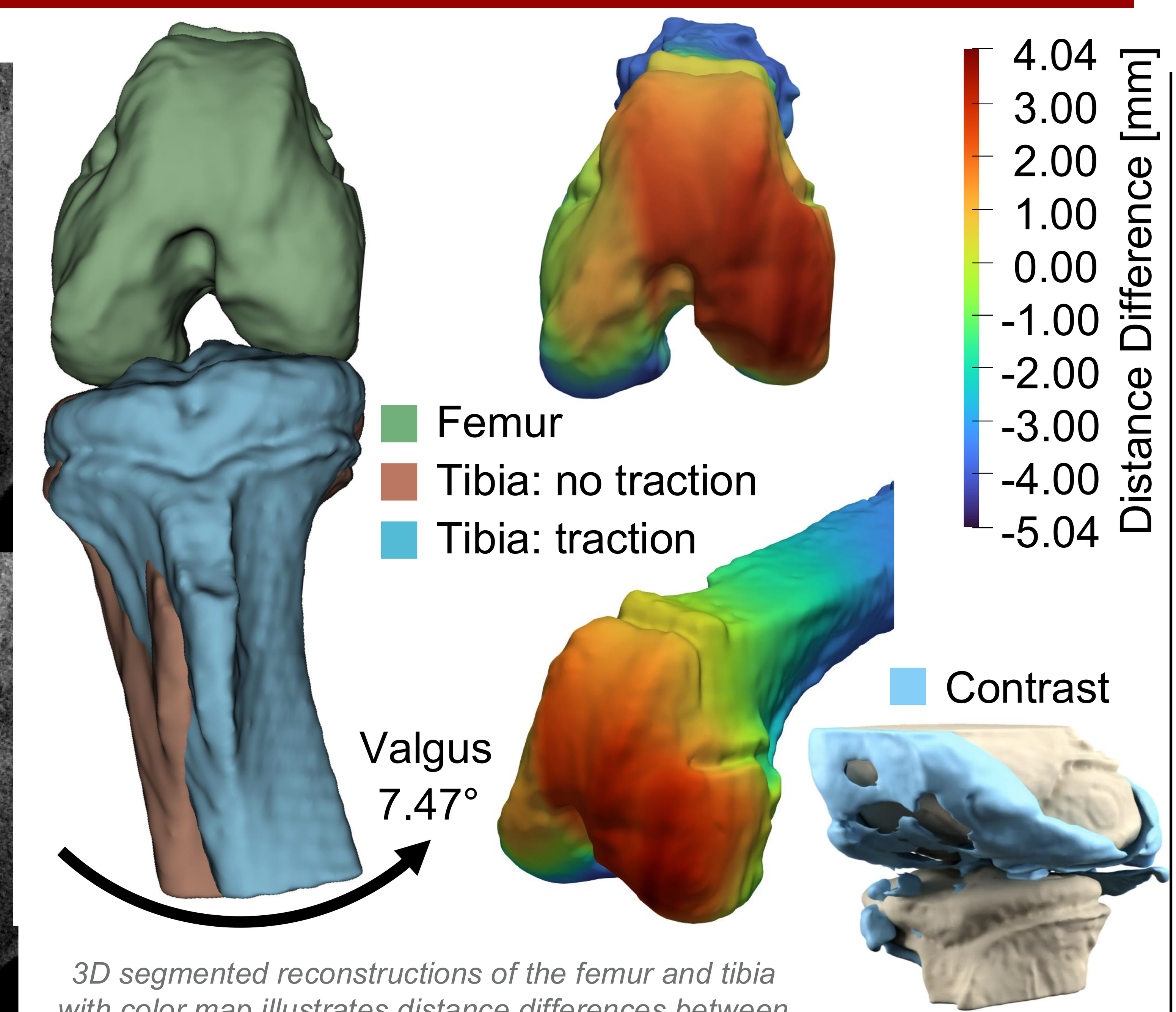
(1) Flexion wedge pillow is used for stable flexed positioning of the leg. (2) Ankle brace is used to connect the traction device to the leg. (3) A pulley to transmit force, and (4) an adjustable weight to deliver sustained traction. (5) Traction module secured to the patient and positioned for scanning within the PCCT bore.

Prototype design: Modular frame stabilizes weight-based pulley system, which applies axial load (2.3-11.3 kg in adjustable 2.3 kg increments). Flexion wedge secures patient knee at 60°

Experimental Porcine Stifle CT Scan



Anterior-posterior and lateral CT views of the porcine stifle under non-contrast and contrast enhanced conditions with no traction applied.



3D segmented reconstructions of the femur and tibia with color map illustrates distance differences between the tibial surfaces in traction and no traction conditions.

Imaging Setup

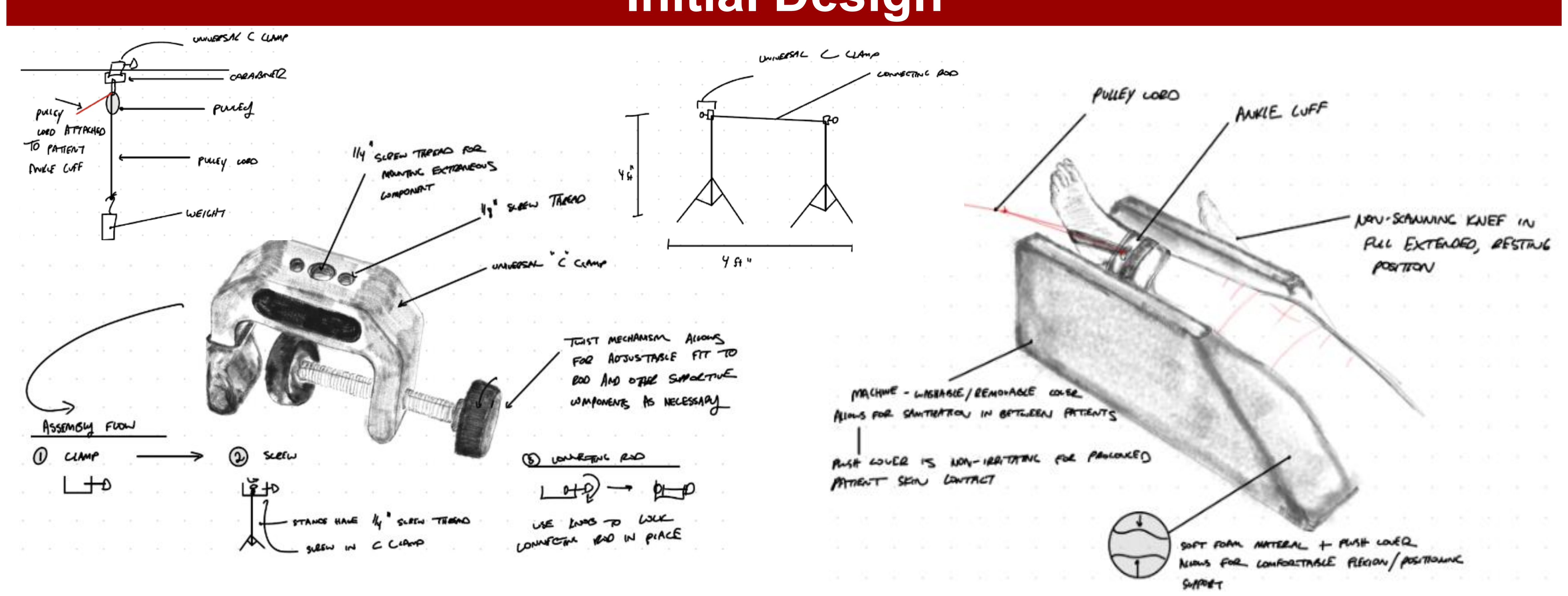
- Fresh porcine cadaver was used to evaluate effectiveness of FlexTrac system
- Non-contrast and contrast scans were performed to compare joint space visibility
- Tibial traction was applied in incremental loads to evaluate its effect on joint separation
- Imaging data was reconstructed into 3D surface models for displacement mapping quantitative measurement of condylar spacing

Results

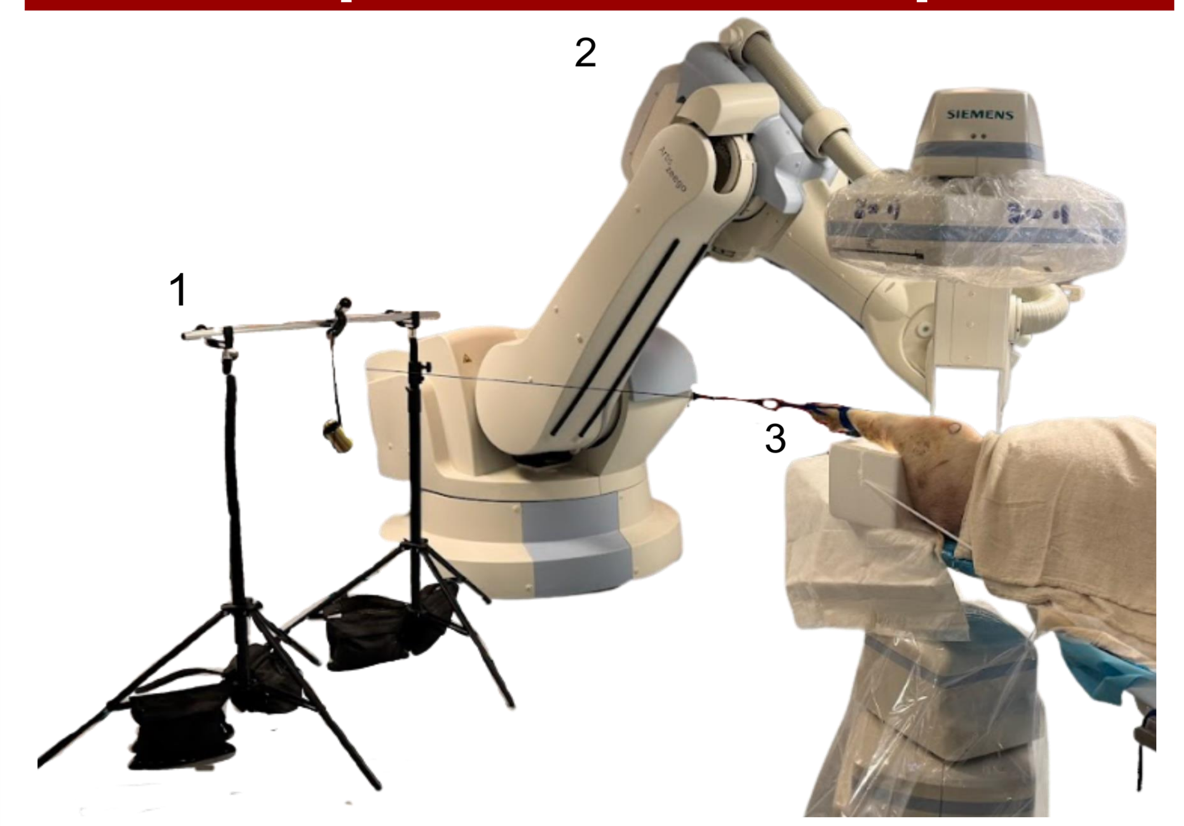
- 11.3 kg traction increased medial condyle spacing by 2-3 mm, minimal changes laterally
- Measurable joint space modulation using FlexTrac

	Medial Condyle [mm]		Lateral Condyle [mm]	
	Mean	99th percentile	Mean	99th percentile
No traction	12.55	24.12	11.85	26.46
Traction	14.94	27.65	11.16	23.99
Difference	2.39	3.53	-0.69	-2.46

Initial Design



Experimental Setup



(1) FlexTrac system (2) Zeego system (3) Porcine is positioned in scanner with traction applied.

- Zeego robotic C-arm system enabled multi-angle imaging of porcine stifle joint under varying traction conditions (2.3-11.3 kg in 2.3 kg increments)
- Contrast-enhanced and non-contrast scans were collected to evaluate joint space changes and imaging clarity
- Displacement was quantified by comparing tibial and femoral positions with/without traction via 3D CT reconstructions

Future Steps

- **Patient Stability:** Patient movement can be further minimized with additional stabilization features
- **Angle Optimization:** Test and compare multiple angles to determine optimal position for maximizing knee joint space
- **Weight Application:** Based on clinician input, upper traction limit is 20-30% of patient body weight. Evaluate FlexTrac under higher loading conditions to assess patient comfort, effectiveness of joint space opening, and stability
- **Extended Testing:** Conduct extended comfort trials by simulating full 1-hour imaging sessions on scan bed

References

[1] Kikuchi, N., *et al*. Improving visualization of the articular cartilage of the knee with magnetic resonance imaging under axial traction: a comparative study of different traction weights. *Skeletal Radiology* 51, 1483–1491 (2022).

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