From CT scan to silicone: rebuilding a kidney for surgical testing

A CT-Derived Silicone Kidney Phantom for Mechanical Testing of Nephroscope Navigation

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1. MOTIVATION / RESEARCH QUESTION

Percutaneous nephrolithotomy (PCNL) treats kidney stones via a nephroscope navigated into the renal collecting system, a minimally invasive alternative to open surgery. Validating new nephroscopes designs requires a testbed with realistic anatomy, but no commercial CT-derived phantom had a collecting system large enough for Dexterous Endoscopes' initial validation tolerances, motivating a custom silicone phantom.

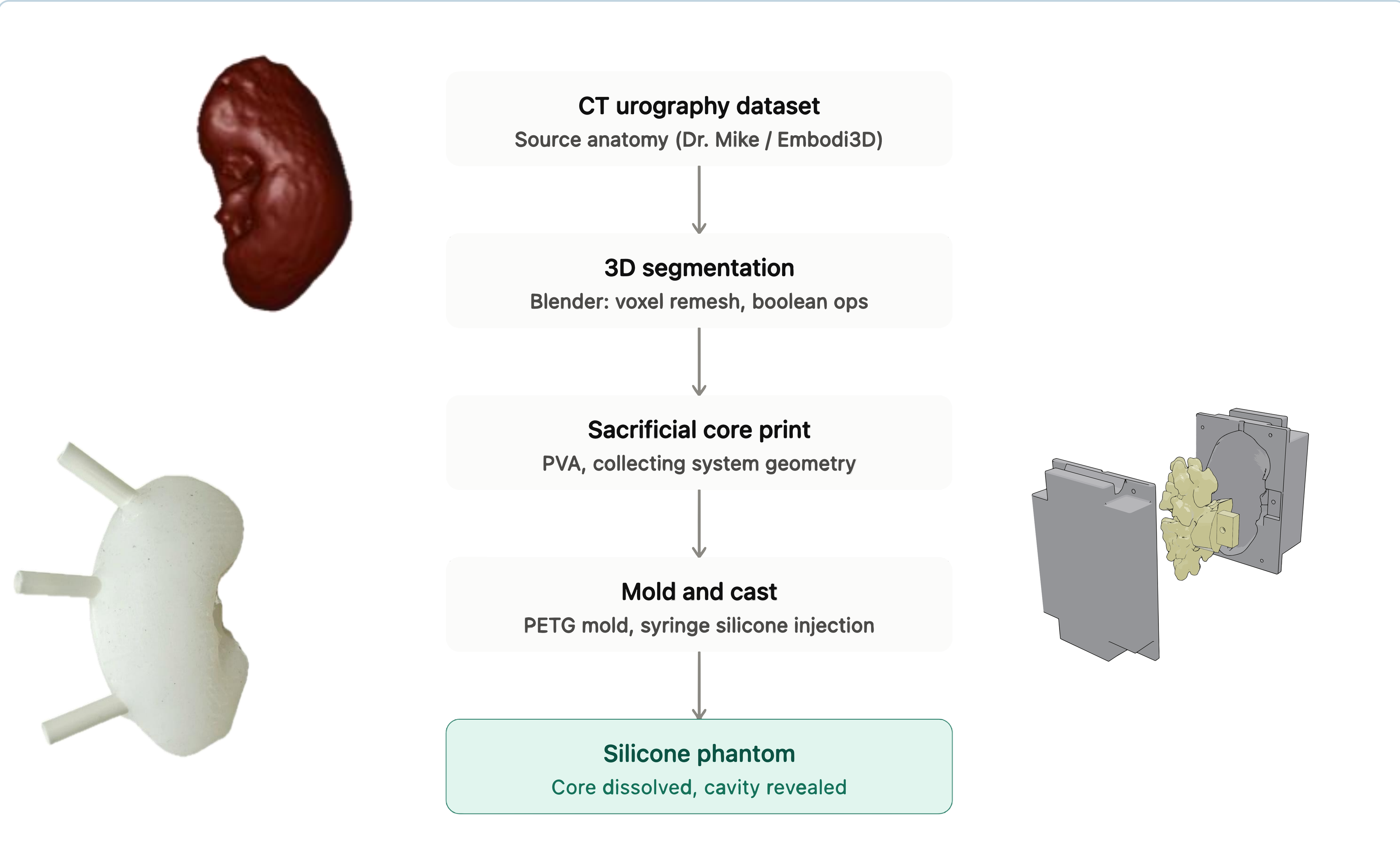
Research question: Can a CT-derived silicone phantom reproduce sufficient geometric accuracy to serve as a validated navigation testbed?

2. BACKGROUND

Because renal anatomy varies significantly between patients, a navigation testbed's value depends on how faithfully it reproduces a real, patient-derived geometry, rather than an idealized or averaged shape (Adams et al., 2017).

Dimensional accuracy against the source CT model is therefore the relevant benchmark for this phantom, though it does not by itself capture inter-patient anatomical variability.

3. METHOD



Fabrication pipeline from patient imaging to the finished phantom

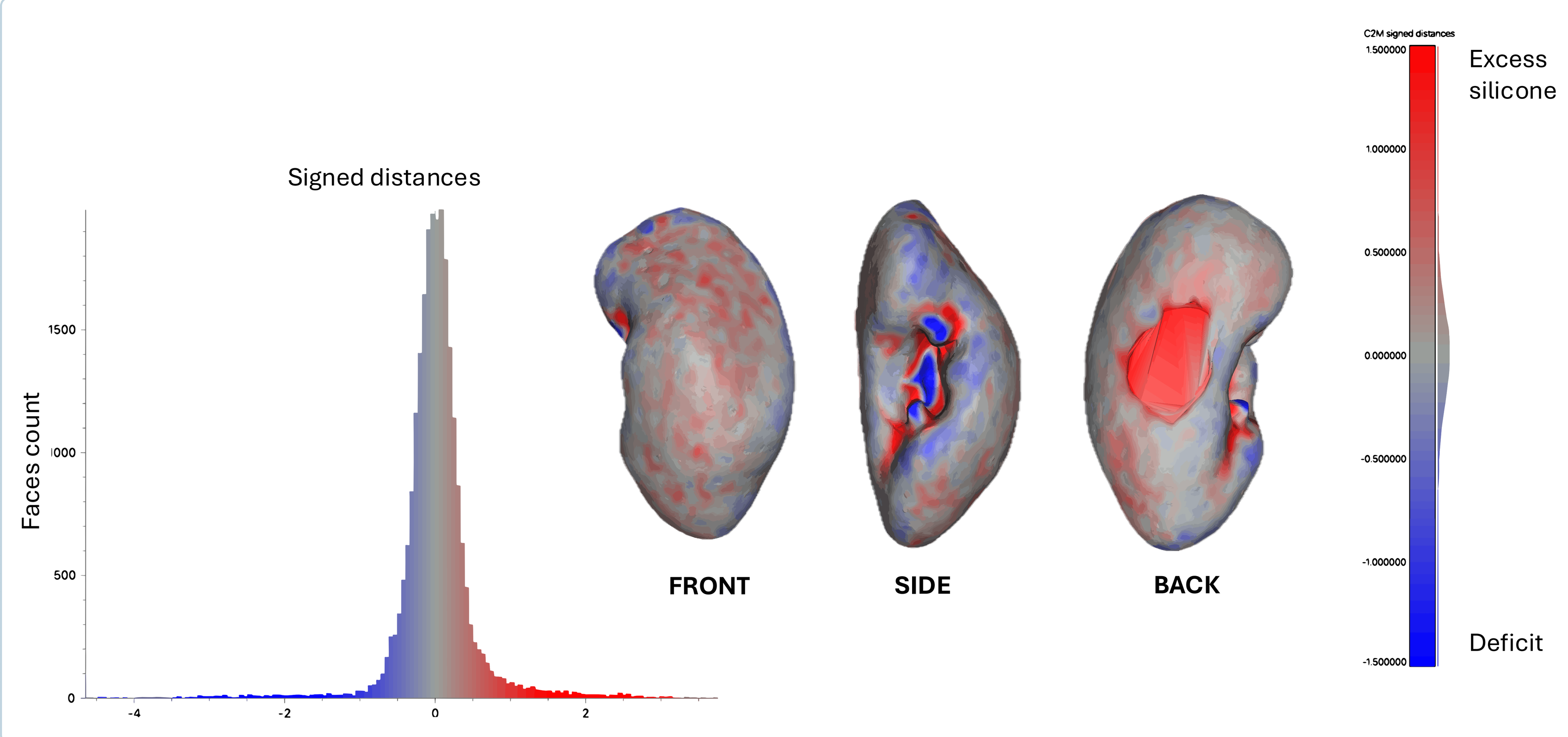
- Mold designed as a two-part shell with air vents, heat-set insert and nut sockets, and a syringe injection port at the base.
- Silicone (Dragon Skin 20/30, Ecoflex 00-30) injected from the bottom via syringe, an iteration from earlier top-fill designs that trapped air pockets.
- PVA core dissolved in water post-cure, leaving the hollow collecting system intact inside the silicone

REFERENCES & ACKNOWLEDGEMENTS

Thanks to Yegor Piskarev and Yi Sun (Dexterous Endoscopes) and Prof. Dario Floreano (LIS, EPFL) for supervision, and the Laidlaw Scholars Programme for support. Base kidney geometry sourced from a CT-derived STL publicly shared on Embodi3D by user "Dr. Mike.»

Adams, F., Qiu, T., Mark, A., Fritz, B., Kramer, L., Schlager, D., Wetterauer, U., Miernik, A., & Fischer, P. (2017). Soft 3D-printed phantom of the human kidney with collecting system. *Annals of Biomedical Engineering*, 45(4), 963–972. https://doi.org/10.1007/s10439-016-1757-5

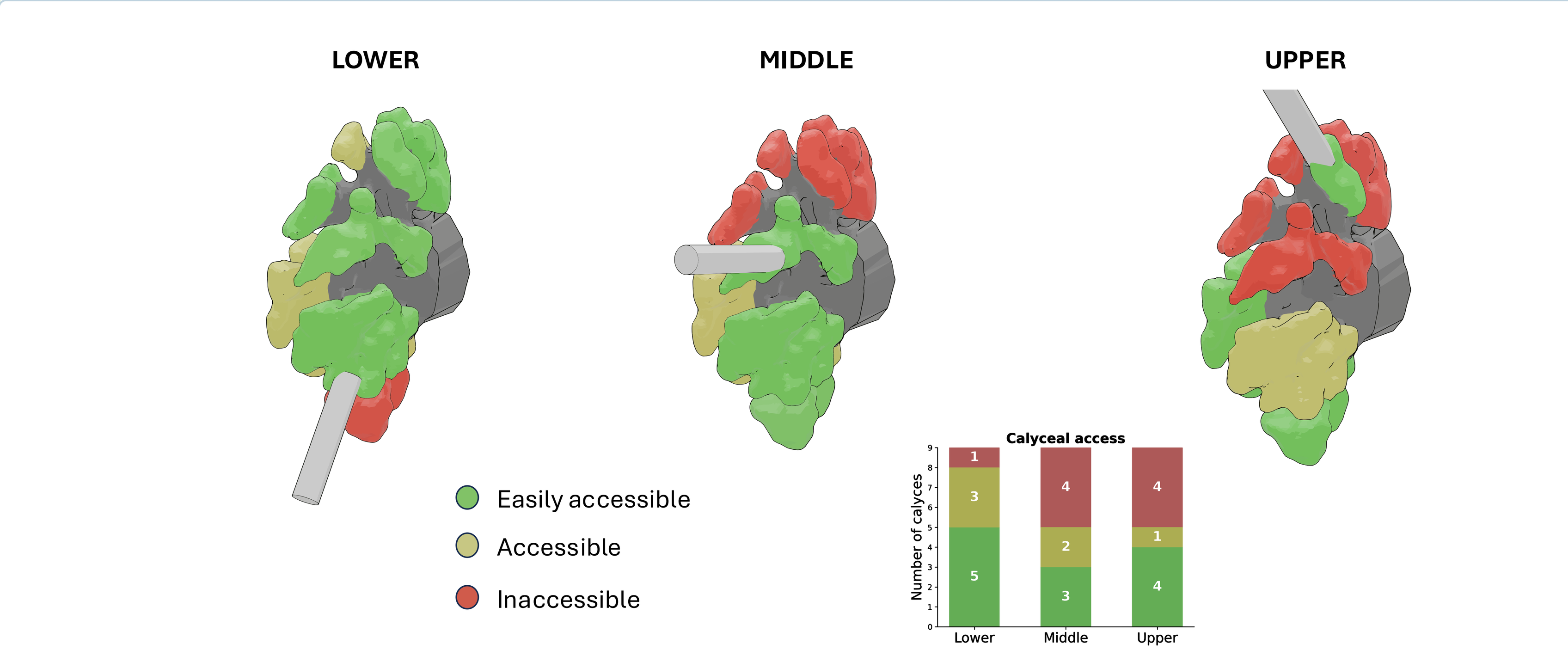
4. DIMENSIONAL ACCURACY



This panel shows the cast phantom colored by its distance to the source CT model. **Caliper measurements** across six external dimensions show 0–1.0 mm absolute error (<1.4% relative), with the cast consistently smaller than the CT reference.

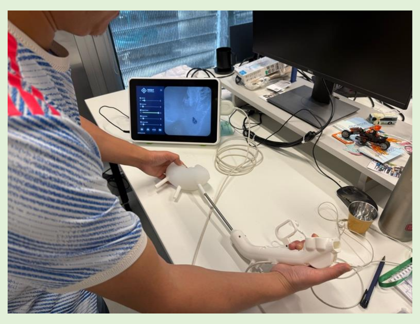
A full-surface **photogrammetry scan** (ICP-aligned) cross-validates this: mean deviation ~0 mm, SD 0.52 mm, with 95% of points within ±1 mm. The near-zero mean reflects spatial averaging, local deficits at the mold seam and hilum are offset by excess at the anterior/posterior faces and residual support silicone.

5. NEPHROSCOPE ACCESS TESTING



Navigation testing of the nephroscope across 3 percutaneous access points assessed reachability of individual calyces within the cast collecting system, evaluating deflection angle / radius of curvature required for calyceal access.

6. DISCUSSION



- Deviations trace to specific causes (design choices and small bulging), and the measured accuracy is sufficient for mechanical navigation testing
- Validation was limited to external geometry via photogrammetry; internal collecting-system accuracy was inferred, as CT re-scanning of the cast was not performed in this work.

7. CONCLUSIONS

- A CT-derived silicone kidney phantom was fabricated using a segmented-core/mold casting pipeline, replicating external kidney geometry within 1.4% dimensional error.
- Percutaneous testing across three access points reached 18/27 calyces (67%) as accessible or easily accessible, 89% from the lower pole vs. 56% from the middle and upper poles.