Endourological Society 2024 Summer Studentship – Project Summary

Student: Ihtisham Ahmad[1]
Supervisor: Dr. Monica Farcas[1,2]

[1] Temerty Faculty of Medicine, University of Toronto, Toronto, ON
[2] Division of Urology, St. Michael's Hospital, Toronto, ON

Flexible Ureteroscopy Simulation with Surgeon, Instrument, and Intrarenal Motion Tracking: Assessing Proficiency Across Training Levels

Introduction:

Flexible ureteroscopy (fURS) is a minimally invasive surgical procedure widely employed for diagnosing and treating upper urinary tract diseases, particularly urolithiasis.[1] The precision required during fURS, along with the intricacy of navigating the kidney's delicate structures, makes this procedure technically challenging. The growing reliance on fURS for stone management necessitates effective and robust training methodologies to ensure that both novice and experienced urologists can develop and maintain the required skills for performing this procedure safely and efficiently.

Traditional methods of surgical training are increasingly being supplemented with simulation-based education.[2] In this context, motion-tracking technology within surgical simulation has gained recognition as a valuable tool.[3,4] By capturing real-time data on instrument movement, motion tracking can provide objective metrics to evaluate a surgeon's performance. This offers a unique opportunity to measure proficiency, allowing trainers to assess skill development across different levels of expertise, from novices to seasoned practitioners. Moreover, it enables a standardized comparison of technique, ensuring that surgical competencies are met as a trainee moves through career stages.

Recently, our lab developed a synchronized motion-tracking system for fURS simulation.[5–7] This system captures surgeon and instrument movement in addition to intrarenal motion of the ureteroscope tip, providing a comprehensive evaluation of the surgeon's ability to manipulate the ureteroscope within the confines of the kidney. The objective of this study was to assess the kinematic parameters between novices and experts during fURS simulation. By doing so, we aim to establish objective benchmarks for training and skill progression in this crucial surgical technique.

Methods:

Simulator and simulation design:

The simulation setup consisted of a 3D-printed kidney based and ureter model based on a patient CT scan (Fig. 2) housed within a standardized ureteroscopy simulation box filled with water (Fig. 1). A standard disposable digital flexible ureteroscope was provided.

Participants were tasked with navigating the through the kidney and mapping all renal calyces that they encountered on a paper after the trial. A staff endourologist viewed the scope live feed for each trial and evaluated participant performance using the URS global rating scale,[8] scoring participants out of 20.

Motion tracking system:
Our comprehensive motion-tracking system involved sensors on the ureteroscope body (Fig. 3), on the deflection-control lever (Fig. 3), on the intrarenal tip (Fig. 4), and incorporated a live video feed of the participant (Fig. 5A). In addition, a separate live video feed of the intrarenal ureteroscope view was recorded to be correlated with motion tracking elements (Fig. 5C). The sensors on the ureteroscope body utilized 6 degrees of freedom in space (x, y, z, roll, pitch, & yaw). Similarly, the sensor at the distal tip utilized 6 degrees of freedom in space. A potentiometer was attached to the control lever that measured deflection as a percentage of maximum resistance. The live video feed of the participant during the trial was analyzed with an automatic computer program that identified the movement of the shoulder, elbow, wrist, and index finger joints to capture the angles and spatial positioning between them (Fig. 5B). The x, y, and z coordinates from the live video correspond to a frontal view, side view, and bird's eye view of the participant as outlined in Fig. 6. Collectively, this system generated detailed metrics of the participant's instrument handling and limb movement. A summary of kinematic parameters generated from our system included: 6 degrees of freedom of the scope, tip, and participant; the angles and locations of the participants' joints; the magnitude of lever deflection used; and the intrarenal path length traveled as well as speed of the intrarenal tip.

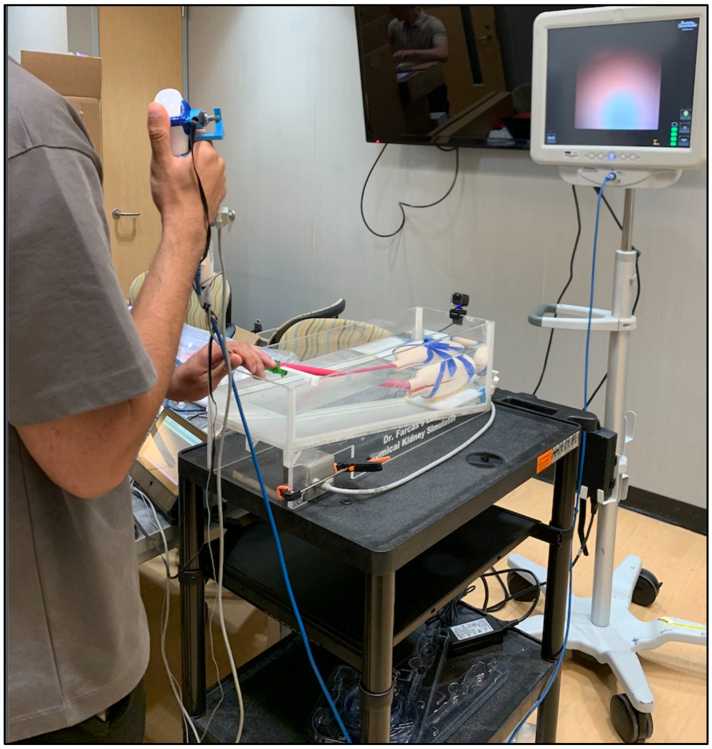

Figure 1: Design of our flexible ureteroscopy simulator.

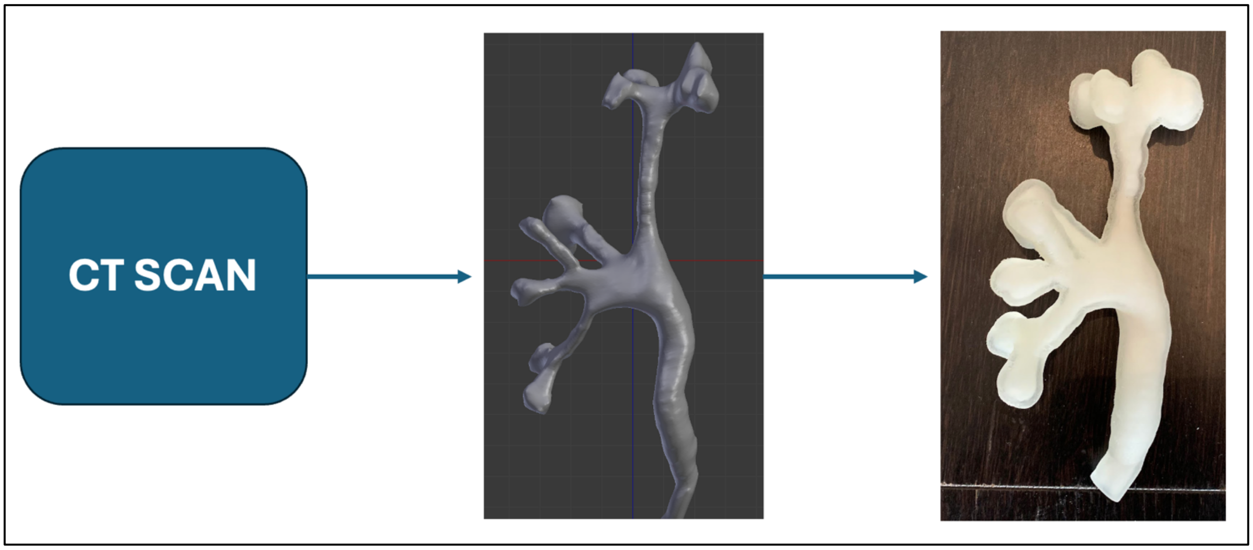

Figure 2: Our 3D-printed kidney model based off patient CT scan.

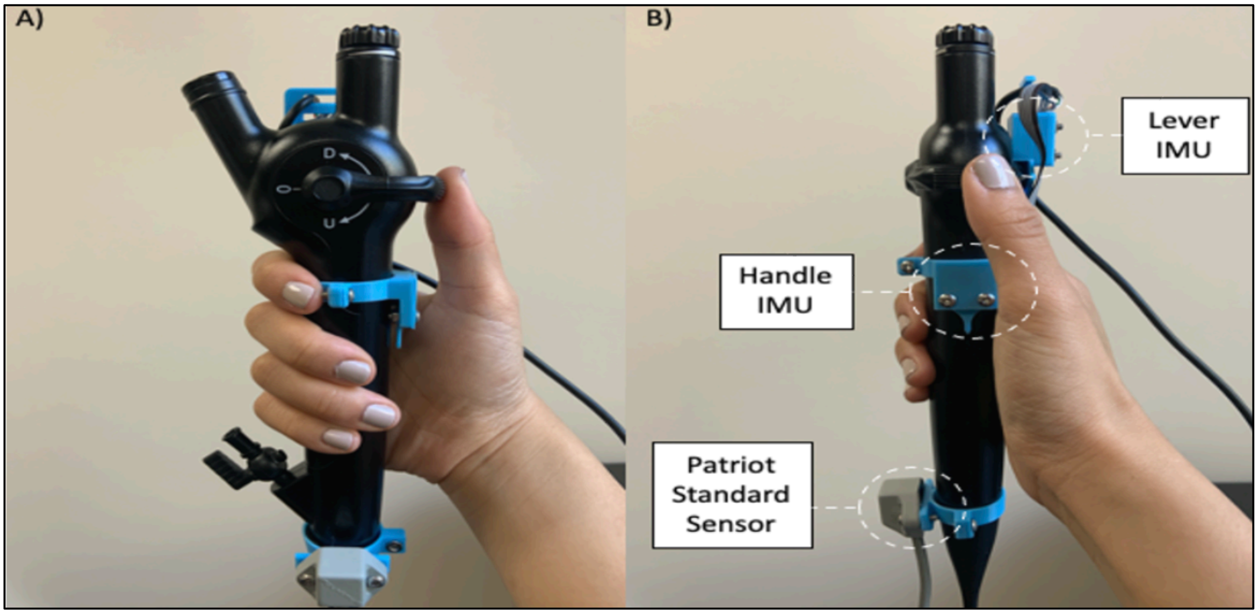

Figure 3: Side view (A) and operator view (B) of motion sensors clamped to the ureteroscope body and lever.

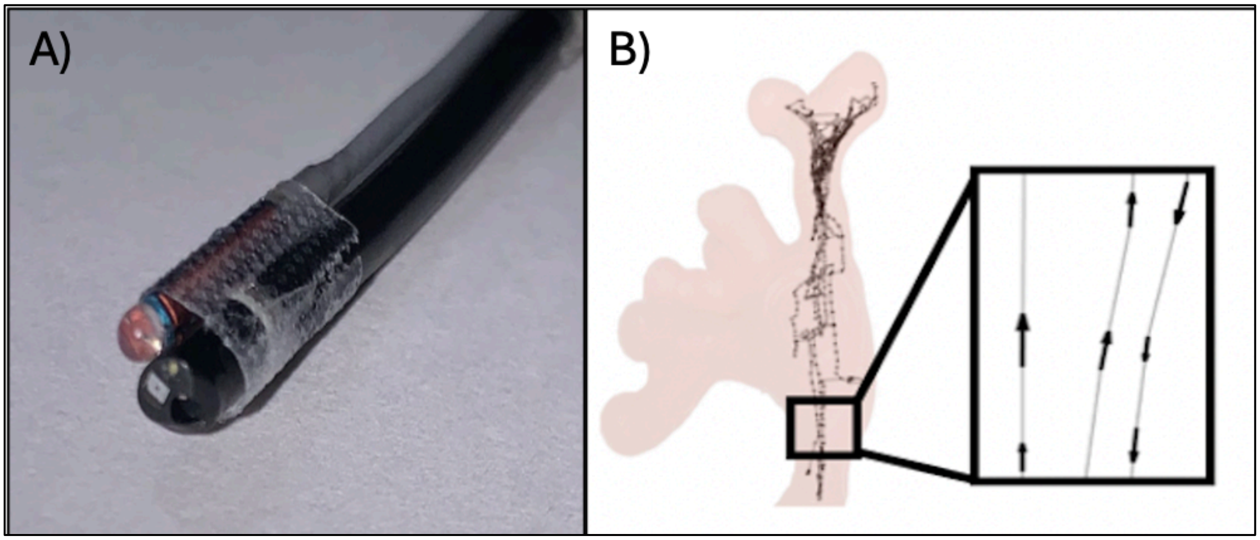

Figure 4: Micro-sensor attached to the tip (A) of the ureteroscope that tracks intrarenal motion (A) with an example of how location and direction are recorded in real time (B).

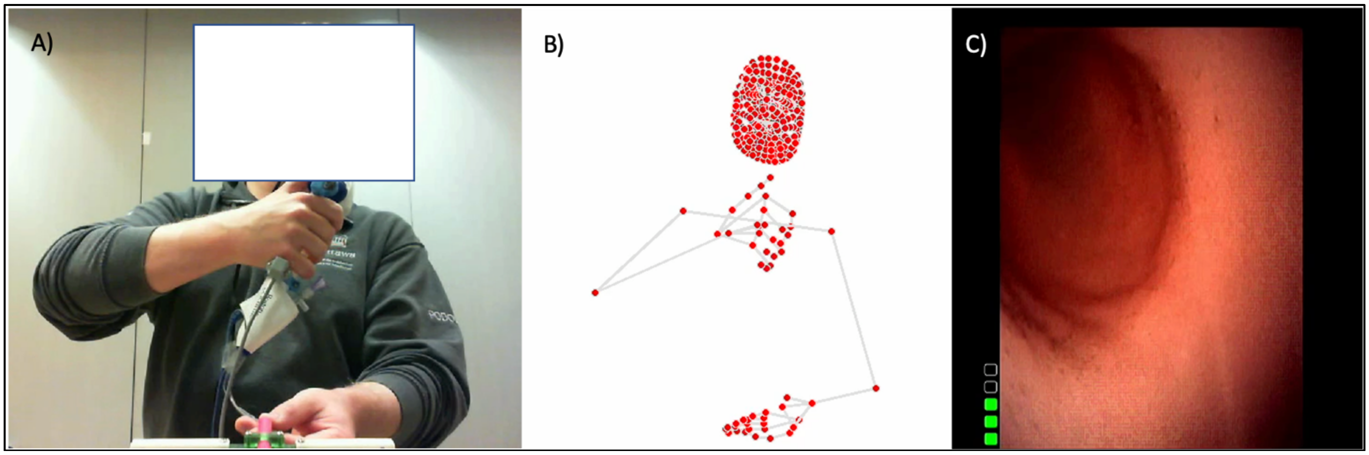

Figure 5: Display of the participant video feed (A), live spatial analysis of joint movement (B), and intrarenal video feed (C) for correlation.

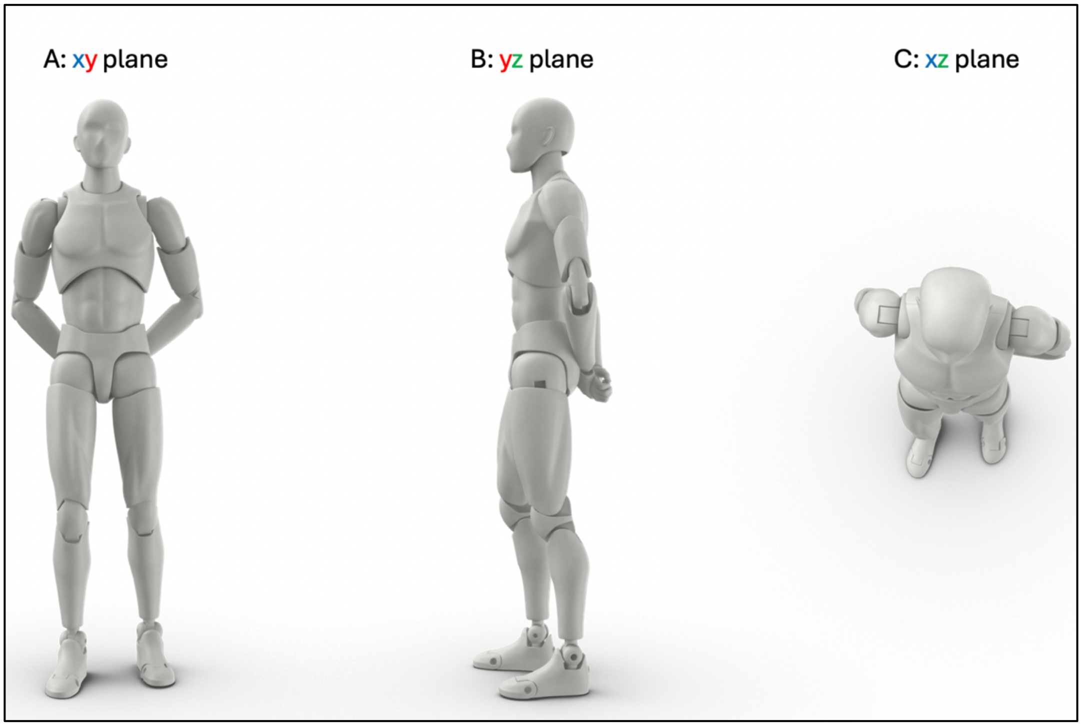

Figure 6: Viewpoints for live video feed motion analysis as defined by our coordinate system, where the xy plane is the frontal view (A), the yz plane is the side view (B), and the xz plane is the top view (C).

Results:

Our preliminary trial recruited 8 participants, consisting of 7 residents (novice group) and 1 urology staff (expert). Our most preliminary analysis presented in this report compared the position of a participant's wrist, elbow, as well as shoulder from video feed, and a visual representation of intrarenal tip motion. Other kinemetric parameters and URS globing rating scale were planned to be incorporated with a follow-up larger trial cohort. For this report, we show the results of our 1 expert participant and 2 of our novices to illustrate differences.

Motion analysis of the live video feed shows less positional variability in our expert participant (Fig. 7), compared to our novice participants (Fig. 8). Specifically, in the xz plane (top view), the expert exhibits a two-tailed tighter distribution than both novices. It is notable as well that the expert exhibits minimal shoulder movement while both novices exhibit relatively greater shoulder movement in the yz plane (side view) and xz plane (top view). Path tracking of the intrarenal tip position during simulation similarly shows differences between our expert participant (Fig. 9A) and novices (Fig. 9B & 9C). Novices spend more time at the upper poles compared to our expert who only visited the upper pole once. Our expert was also able to completely explore the lower calyx compared to our novices who did not record as many instances as far into the lower calyx. Lastly, we can see that our expert had a greater focus on remaining in the renal pelvis while scoping into other calyxes, while novices reached the terminal tissue of each calyx that they explored with the tip. This may be related to confidence from the expert participant that they had observed the interior of the calyx without fully advancing the scope into it and increasing risk of tissue damage.

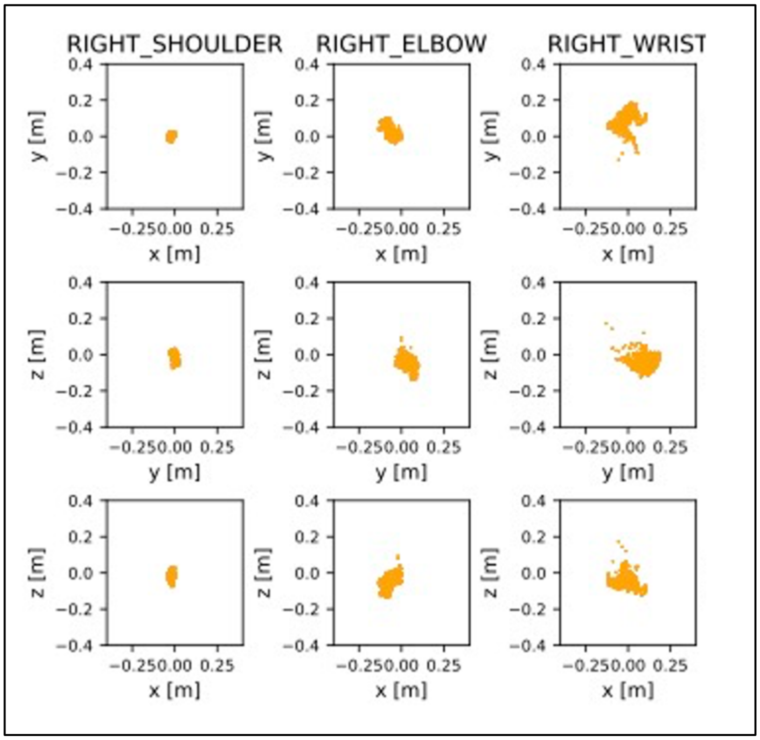

Figure 7: Motion analysis of the position of different joints during flexible ureteroscopy simulation from live video feed of an expert endourologist.

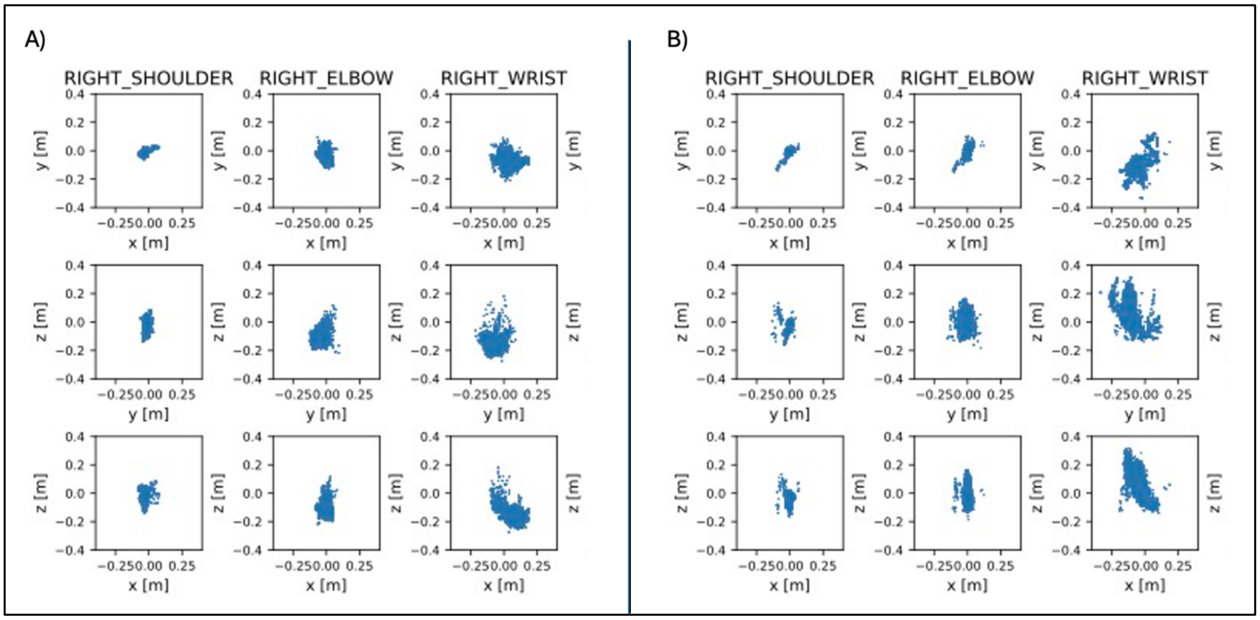

Figure 8: Motion analysis of the position of different joints during flexible ureteroscopy simulation from live video feed of novice A and novice B.

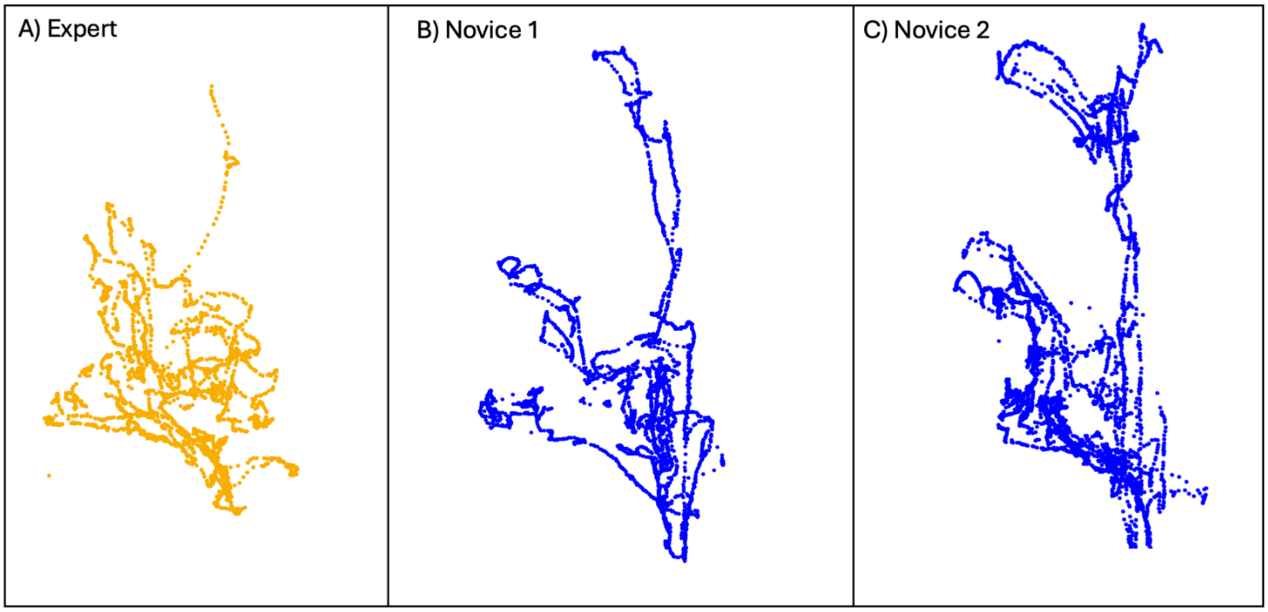

Figure 9: Visualizing intrarenal motion during flexible ureteroscopy simulation with tip motion tracking of an expert (A) and novices (B & C).

Discussion:

Our novel motion-tracking system for flexible ureteroscopy (fURS) simulation demonstrates significant potential to advance both the training and assessment of surgical proficiency. By integrating sensors that capture kinematic data, this system provides a comprehensive evaluation of instrument handling, body movement, and intrarenal navigation. The capability of tracking motion with visual and numeric data allows for the generation of objective metrics that can assess skill level. This real-time feedback may prove valuable in providing personalized learning experiences, allowing trainees to focus on specific aspects of their technique that need improvement.

Our preliminary cohort demonstrated the potential of this system to differentiate between novice and expert performance based on an assortment of motion tracking parameters. For example, expert surgeons tend to follow more efficient and consistent paths during fURS procedures, exhibiting less variability in their movements. In contrast, novice surgeons often show greater variability in their movement patterns, with less controlled navigation and higher path lengths. Visualizing the intrarenal movements show that novices may have difficulty with accessing the lower calyxes and rely more on completely entering a calyx with their scope than experts who can be more confident with their visualization. These differences, captured through motion tracking, offer clear, objective benchmarks for skill acquisition and progression.

This technology is still in its early stages. We have not included in this report analysis for 6 degrees of freedom of the scope and tip, measurements of lever deflection, and measurements of speed and acceleration of the tip. As well, next steps include correlating kinematic metrics with the URS global rating scale[8] as a means of construct validity. We did collect URS global rating scale scores for our participants and this analysis is pending. Differentiating which specific metrics among the abundance of data that our system can collect are useful is a critical missing piece. Lastly, the recruitment and testing of a large cohort of novices and experts across the learning curve of URS is needed to get a robust dataset before conclusions can be drawn.

Conclusion:

In summary, our motion-tracking system demonstrates potential in enhancing simulation-based surgical education. The ability to capture detailed, objective data on surgeon performance opens new avenues for both personalized learning and broader educational standardization. By refining this system and expanding its applications, we hope to contribute meaningfully to the improvement of surgical training, ultimately leading to better outcomes for patients undergoing endourological and other minimally invasive procedures.

References:

1. Ankem MK, Lowry PS, Slovick RW, Munoz del Rio A, Nakada SY. Clinical utility of dual active deflection flexible ureteroscope during upper tract ureteropyeloscopy. *Urology*. 2004;64(3):430-434. doi:10.1016/j.urology.2004.04.011

2. Lu J, Cuff RF, Mansour MA. Simulation in surgical education. *Am J Surg*. 2021;221(3):509-514. doi:10.1016/j.amjsurg.2020.12.016

3. Nasr A, Carrillo B, Gerstle JT, Azzie G. Motion analysis in the pediatric laparoscopic surgery (PLS) simulator: validation and potential use in teaching and assessing surgical skills. *J Pediatr Surg*. 2014;49(5):791-794. doi:10.1016/j.jpedsurg.2014.02.063

4. Ebina K, Abe T, Higuchi M, et al. Motion analysis for better understanding of psychomotor skills in laparoscopy: objective assessment-based simulation training using animal organs. *Surg Endosc*. 2021;35(8):4399-4416. doi:10.1007/s00464-020-07940-7

5. Trac J, Lee J, Fok KH, Carrillo B, Farcas M. Development of a synchronous motion-tracking and video capture tool for flexible ureteroscopy. *Can Urol Assoc J*. 2024;18(4):103-109. doi:10.5489/cuaj.8530

6. Lee J, Ahmad I, Fok KH, et al. MP43-05 DEVELOPMENT OF A NOVEL SIMULATION SYSTEM FOR FLEXIBLE URETEROSCOPY WITH TIP AND HAND MOTION TRACKING. *J Urol*. 2024;211(5S):e694. doi:10.1097/01.JU.0001008720.96896.83.05

7. Ahmad I, Lee J, Fok KH, et al. MP73-03 FLEXIBLE URETEROSCOPY SKILL DEVELOPMENT: A PILOT COMPARATIVE STUDY USING MOTION-TRACKING

SIMULATION WITH TIP TRACKING. *J Urol*. 2024;211(5S):e1182. doi:10.1097/01.JU.0001009564.26544.1c.03

8. Goldenberg M, Ordon M, Honey JRD, Andonian S, Lee JY. Objective Assessment and Standard Setting for Basic Flexible Ureterorenoscopy Skills Among Urology Trainees Using Simulation-Based Methods. *J Endourol*. 2020;34(4):495-501. doi:10.1089/end.2019.0626