



Original Research Article

Gender differences in ergonomics during simulated ureteroscopy

Erin Kim^{a,*}, Alec Sun^a, Juan Sebastian Rodriguez-Alvarez^b, Louisa Ho^b, Kyle O'Laughlin^c, Smita De^b^a Case Western Reserve University School of Medicine: 9501 Euclid Ave, Cleveland, OH, 44106, USA^b Cleveland Clinic Glickman and Urological Kidney Institute, 9500 Euclid Ave Q10, Cleveland, OH, 44195, USA^c Cleveland Clinic Lerner Research Institute Department of Biomedical Engineering: 9500 Euclid Avenue Lerner Research Institute/ND-20, Cleveland Clinic, Cleveland, OH, 44195, USA

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ABSTRACT

Background: Female urologists report higher rates of work-related physical discomfort compared to male urologists. We compared ergonomics during simulated ureteroscopy, the most common surgery for kidney stones, between male and female urologists.

Methods: Surface electromyography was used to measure muscle activation during common ureteroscopic tasks in urology trainees and staff with different surgeon positions and ureteroscopes. Subjective workload was assessed using the NASA Task Load Index (NASA-TLX). Paired t-tests, Wilcoxon rank-sum tests, and multivariate regressions were used to compare muscle activation by gender for each trial condition.

Results: There was no difference in age or distribution of training level between genders, though men had larger glove sizes. Across all conditions, women required greater muscle activation in multiple muscle groups and had greater NASA-TLX scores compared to men.

Conclusions: There may be gender differences in ergonomics during ureteroscopy based on muscle activation and subjective workload, suggesting potential for personalizing surgical ecosystems.

1. Introduction

Up to 90% of urologists report musculoskeletal pain or discomfort related to their occupation.^{1,2} A higher case load of kidney stone surgeries has been associated with increased orthopedic problems.³ With the intent of minimizing workplace injury and preserving career longevity, especially with physician shortages, ergonomics in the operating room has become a growing field of interest.

Demographic trends in the field of urology are shifting. The number of women in urology is on the rise^{4,5} with over a third of urologists expected to be female by 2062.⁶ Emerging studies suggest that this population experiences higher rates of work-related injuries than their male counterparts,⁷ and correlations have been made between female proceduralists and increased subjective workload.^{8,9} Given the above, poor ergonomic design has been theorized to be a contributing factor to higher rates of burnout in this population,¹⁰ potentially exacerbating existing disparities that women face in surgical subspecialties.

Ureteroscopy is an endoscopic procedure and is the most common surgery performed for kidney stones, a condition affecting more than

10% of the U.S. population.¹¹ Given the rising prevalence of kidney stones and a shortage of urologists, rates of ureteroscopy per surgeon are likely to increase. Ergonomics during ureteroscopy, which often requires heavy ureteroscopes and contortion by the surgeon to access the kidney stones for treatment, has not been well studied, particularly as related to gender. Surface electromyography (EMG) has been used to evaluate ergonomics in surgical settings, though mostly in robotic^{12,13} and laparoscopic^{9,14,15} surgery. Two prior studies have used EMG to quantitatively measure muscle activation during ureteroscopy, but these studies were limited to just a few male subjects.^{16,17} In this study, we aimed to assess differences in muscle activation and subjective workload between male and female urologists during simulated flexible ureteroscopy.

2. Methods

After obtaining institutional review board approval, urology trainees and staff at our institution were recruited for the study. Inclusion criteria included urologists of age ≥ 18 , employment as a current resident, clinical fellow, or junior attending in the Urology department, and

* Corresponding author.

E-mail address: egk48@case.edu (E. Kim).<https://doi.org/10.1016/j.amjsurg.2024.02.034>

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completion of at least 9 ureteroscopy procedures to confirm proficiency.¹⁸ Individuals were excluded if they had any recent orthopedic injury, were pregnant, had not been trained in ureteroscopy, had a known neuromuscular disorder, or had been an attending urologist for greater than 5 years. Senior attending surgeons were excluded as they may have difficulty accommodating to surgical positions or ureteroscope types not used in their standard practice whereas trainees and junior faculty were familiar with the equipment and techniques for all the test conditions in the study.

Gender (male, female, or other), years of urological training, glove size, age, height, weight, exercise, and use of glasses were reported by each participant. In this study, we used the term gender to represent biologic sex with the understanding that these are not always concordant. All data collection took place in a procedural room set up to emulate an operating room (Fig. 1) with an adjustable height patient table with extended leg stirrups, adjustable surgeon stool, and video endoscopy tower.

Participants were instructed to adjust table and stool heights to their preference. Each participant was asked to wear their own lead apron (including thyroid shield), or if they did not have one, then to choose a common one they felt fit them well throughout the experiment.

Surface EMG stickers were placed on the following muscle groups on the dominant (ureteroscope-driving) arm following SENIAM guidelines¹⁹: thenar, forearm extensor, forearm flexor, biceps, triceps, deltoid, trapezius, and neck extensor (Fig. 2).

Maximum voluntary contraction (MVC) was measured for each muscle group three times with a 1-min break in between, and the mean MVC was used to establish the baseline for each participant. Participants then performed the following three simulated flexible ureteroscopy tasks in randomized order.

- Navigation: Maneuver ureteroscope through a kidney collecting system box trainer (Cook Medical LLC, Bloomington, IN) (Fig. 3A) to pre-labeled sequential targets (Fig. 3B).
- Dusting: In the box trainer renal system, deflect the ureteroscope tip continuously between four dots to mimic the action of dusting a stone with a laser for 5 min (Fig. 3C).
- Basketing: Insert ureteroscope through a ureteral access sheath (Boston Scientific, Marlborough, MA) into a silicone model kidney with ureter (Simagine Health Inc., Seattle, WA) (Fig. 3D) containing stone phantoms (Fig. 3E); locate a stone and hold position for 5 s to emulate time taken to grasp the stone with a basket, remove



Fig. 2. EMG sensor placement, anterior view.

ureteroscope (like extracting a stone fragment with the basket), repeat process in adjacent calyces for a total of 20 basketing actions per trial.

Each set of 3 tasks was performed while the participant was sitting, standing, and with both a single-use (WiScope®, BD, Franklin Lakes, NJ) and a reusable ureteroscope (Viper™, Richard Wolf Medical Instruments Corporation, Vernon Hills, IL). There was a rest period of 1 min following completion of each task during which the participant used their non-dominant hand to fill out the National Aeronautics and Space Administration Task Load Index (NASA-TLX), a validated tool to assess perceived workload for the trial they just completed.²⁰ The NASA-TLX quantifies subjective workload across six subscales: mental demand, physical demand, temporal demand, effort, performance, and frustration level.²¹ After each task, participants ranked each of the subscales from low to high (corresponding to a numerical score up to 100) on the official NASA-TLX application developed for mobile devices.²² Each participant then completed a series of 15 pairwise comparisons to determine the weight for each subscale. The weights were then used to calculate the individual weighted subscale scores. For each participant, the sum of these weighted subscales was divided by 15 in order to calculate the weighted overall NASA-TLX score for each trial condition.²³

The protocol for assessing %MVC was established based on published protocols and standard practice for electrophysiology studies at our institution.^{24,25} Raw EMG signals were recorded with a sampling rate of 4000 Hz and processed with a high pass filter (cut-off frequency of 10 Hz). The filtered EMG signal was full-wave rectified by taking the absolute value and then smoothed using the square root to give the root-mean-square (RMS) EMG. For each trial, percent maximum voluntary contraction (%MVC) was calculated by dividing the RMS EMG for a given muscle by the individual's mean baseline MVC for that muscle (which was established at the beginning of the experiment).

To compare %MVC to trial conditions and gender, Wilcoxon rank-sum tests and paired t-tests were completed as appropriate ($\alpha = 0.05$). Pearson's correlation coefficients (r) were calculated to assess relationships between %MVC and years of training. NASA-TLX weighted overall scores were aggregated for each of the trial conditions and compared between male and female surgeons with Wilcoxon rank-sum tests. Each of the NASA-TLX weighted subscales were also separately compared by



Fig. 1. Example room set up. Not pictured: surgeon stool.

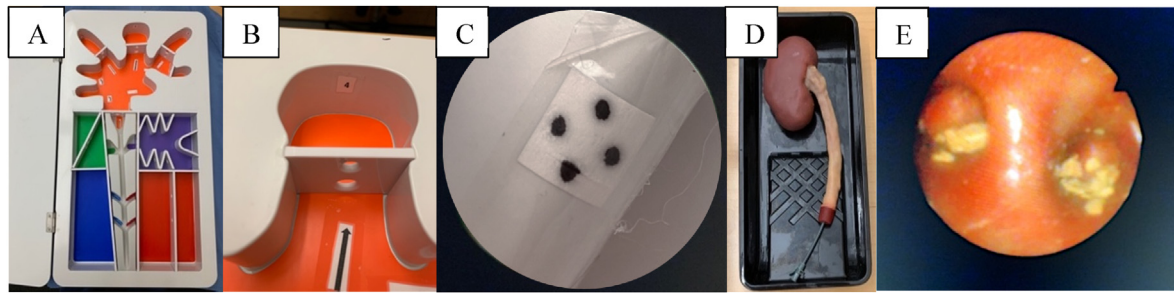


Fig. 3. a) Kidney collecting system box trainer, lid open, birds-eye view, used for navigation and dusting tasks; B) Kidney collecting system box trainer, example of pre-labeled target used for navigation task; C) Dots for dusting task; D) Silicone model kidney for basketing task; E) Stone phantoms in silicone model kidney for basketing task.

gender across all trial conditions. Multivariate linear regressions were conducted to determine significant predictors of %MVC and to assess interactions between trial conditions. Predictor variables included gender and one trial condition (posture, task, ureteroscopy type). Interaction terms were considered if both gender and trial condition predictors were significant.

3. Results

3.1. Participant characteristics

There were a total of 14 participants (Table 1) with no significant difference in age or urologic training level between males and females. There was no correlation between training level and %MVC of any muscle (correlation coefficients for all muscles $r < 0.2$). Men had a higher mean glove size than women (7.5 vs. 6, $p = 0.001$) as well as higher heights and weights. None of the participants had exercised the day of data collection, and there was no significant difference between the number of men and women who had exercised the day prior. Of note, neck extensor muscle activation was excluded from further analysis as EMG artifacts resulted in over 100% MVC in multiple trials. This could have been due to interference or rubbing of the electrodes on the thyroid shield.

3.2. Overall muscle activation by position, task, and ureteroscopy type

There were differences in muscle activation depending on position, task type, and ureteroscopy type regardless of gender. All reported differences are statistically significant ($p < 0.05$) unless otherwise stated (see appendix A).

3.2.1. Position

Across all participants, % MVC was higher in the deltoid and trapezius when sitting vs. standing (3.3% vs 3.0% in deltoid, 6.6% vs 5.5% in trapezius). There were no other differences in muscle activation based on position.

Table 1

Participant Characteristics. Values reported as median [IQR].

	Female (n = 6)	Male (n = 8)	Statistical Significance
Age	30.5 [29, 33]	31 [30.5, 31.3]	$p = 1$
Urologic Training >4 years	3 (50%)	5 (62.5%)	$p = 1$
Glove Size	6 [5.5, 6.5]	7.5 [7.5, 7.5]	$p = 0.001$
Height in centimeters	63 [62, 66]	72.5 [69, 73.3]	$p < 0.001$
Weight in pounds	132 [110, 147]	190 [180, 193.8]	$p < 0.001$
Exercised Today	0	0	$p = 1$
Exercised Yesterday	4	4	$p = 0.6$
Wears glasses	6	6	$p = 0.47$

3.2.2. Task type

When comparing task types across all participants, the forearm extensor had higher %MVC with navigation than with basketing whereas the biceps and trapezius had greater muscle activation with basketing than with dusting (3.71% and 4.2% higher, respectively). The thenar, forearm flexor, and forearm extensor had increased %MVC with navigation than with dusting (4.21%, 3.26%, and 10.1% higher, respectively).

3.2.3. Ureteroscope type

With respect to ureteroscope type, the reusable ureteroscope required greater muscle activation compared to the single-use ureteroscope across multiple muscle groups including the forearm flexor, biceps, triceps and deltoid (absolute differences of 3.9%, 2.9%, 0.6%, and 0.3%, respectively). However, a higher %MVC was measured in the thenar muscle with the single-use ureteroscope than with the reusable ureteroscope (9.6% vs 6.3%).

3.3. Muscle activation and gender

For every trial condition, regardless of task, position, or ureteroscope type, women had higher %MVC compared to men in the majority of muscle groups tested. There were no conditions under which men had greater %MVC than women in any muscle.

3.3.1. Position

When standing, women had greater %MVC than men in the forearm flexor, forearm extensor, biceps, and triceps (Fig. 4). The largest magnitude of difference was in the forearm flexor, in which women had almost 3 times greater %MVC than men (14.3% vs 4.8%, $p < 0.001$). In the sitting position, a higher %MVC was measured in women for the thenar, forearm flexor, forearm extensor, biceps, and triceps.

3.3.2. Task type

During all three tasks, women had significantly greater %MVC than men in the forearm flexor and triceps, with the largest magnitude of difference measured in the forearm flexor (ranging from 11.1% to 7.4%). When basketing, there were also significant differences between genders in activation of the thenar and biceps muscles. In the dusting task, women used forearm extensors significantly more than men (15.9% MVC difference), whereas during navigation, both the forearm extensors and biceps were more activated in women (Fig. 5).

3.3.3. Ureteroscope type

Both single-use and reusable ureteroscopes showed greater %MVC for women in the thenar, forearm flexor, forearm extensor, biceps, and triceps (Fig. 6). The largest magnitude of difference was seen in the forearm flexor ($p < 0.001$ for both ureteroscope types). The multivariate regression found a significant interaction term indicating that women experienced a disproportionate increase in forearm flexor %MVC with the

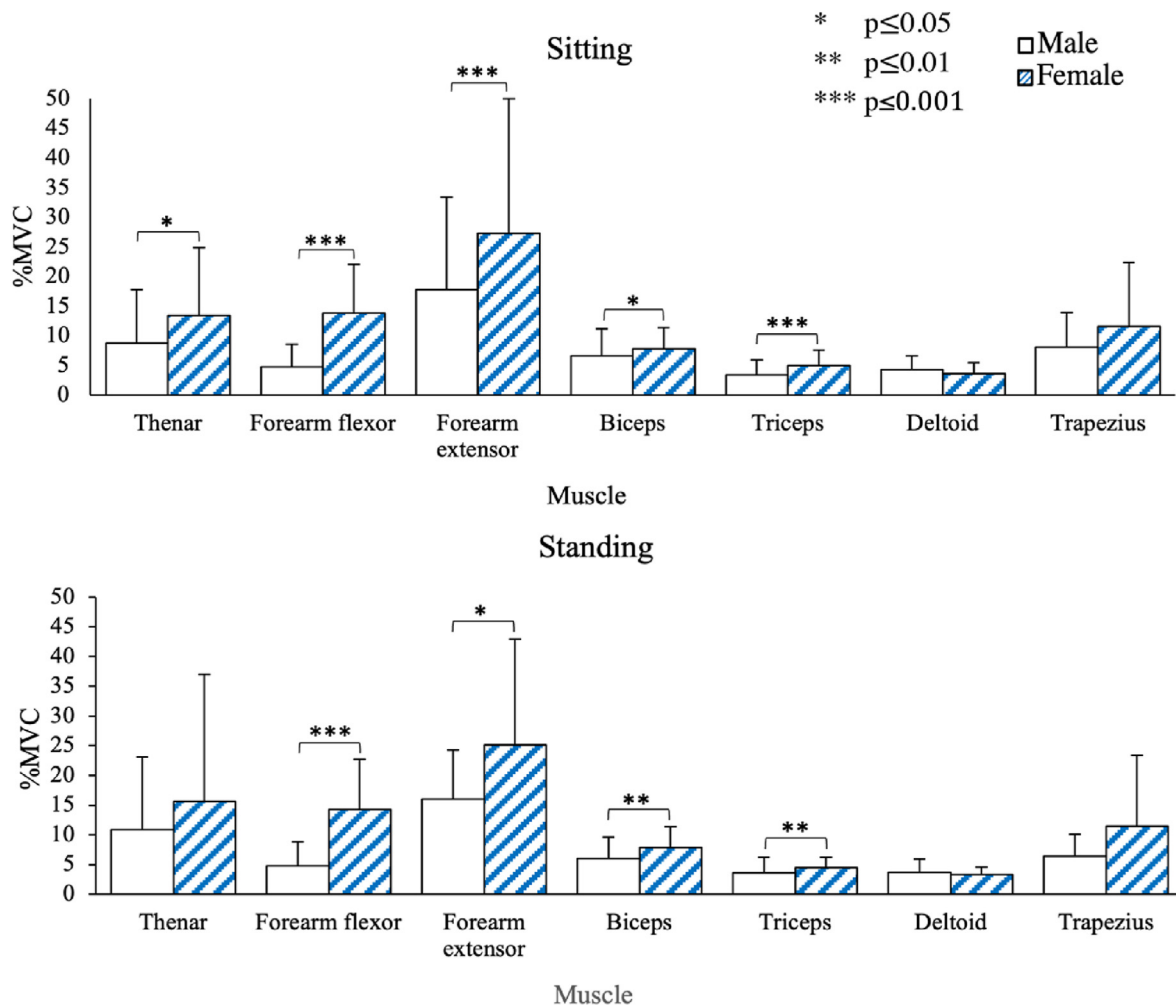


Fig. 4. %MVC in men vs. women while sitting vs. standing.

reusable ureteroscope compared to the single-use ureteroscope. Men used just 1% MVC more with the reusable ureteroscope compared to the single-use ureteroscope, while women relatively used almost 7 times additional effort compared to men.

3.4. NASA Task Load Index and gender

For all positions, ureteroscope types, and task types, women had greater NASA-TLX weighted overall scores than men. When comparing NASA-TLX weighted subscales, on average women reported a higher physical demand than men. All other NASA-TLX weighted subscales showed no significant difference between men and women (Fig. 7).

4. Discussion

This is the first study to quantify differences in ergonomics between men and women as measured by EMG during kidney stone surgery. Overall, women had higher muscle activation and subjective workload compared to men. Investigation of other surgical procedures, such as laparoscopy, have found similar patterns of increased muscle activation in women surgeons compared to men,⁹ but many studies lack adequate gender representation.²⁶

At baseline, regardless of gender, there was greater muscle activation in shoulder and upper back muscle groups (deltoid and trapezius) when sitting compared to standing. This is consistent with our pilot study and likely relates to the increased upper arm movements required to perform tasks such as basketing in the sitting position where the surgeon is closer

to the urethra with less workspace. There were also differences in %MVC based on ureteroscope type, which was to be expected as the reusable ureteroscope is heavier than the single-use ureteroscope (870 g and 144 g, respectively). Notably, the stiffness of the deflection lever of the single-use ureteroscope is subjectively higher, perhaps accounting for the increased thenar activation with the single-use ureteroscope. Additionally, regardless of gender, there were baseline differences based on task type, which was also to be expected since the different tasks required different maneuvers. However, when evaluating each of these variables individually and comparing by gender, women consistently had higher muscle activation in the majority of muscles tested for all trial conditions.

The fact that women utilized equal or greater %MVC than men for every trial condition regardless of position, ureteroscope type, or task may not be entirely surprising given the baseline smaller stature and lower muscle mass typically associated with women. However, the fact that the muscle groups in which these differences manifested differed based on conditions indicates that there could be ways to target solutions for decreasing the disparity between genders.

The statistically significant differences in muscle activation in combination with consistently higher NASA-TLX scores for women for all trials raises the concern that the ergonomic difference is clinically significant enough to affect women surgeons' subjective workload. Notably, physical demand had the highest ranked weight among all subscales for females, and correspondingly, only the physical demand subscale weighted score of the NASA-TLX was significantly higher in females compared to males. This indicates that the difference in workload stems from at least the perception of increased physical demand, if not the

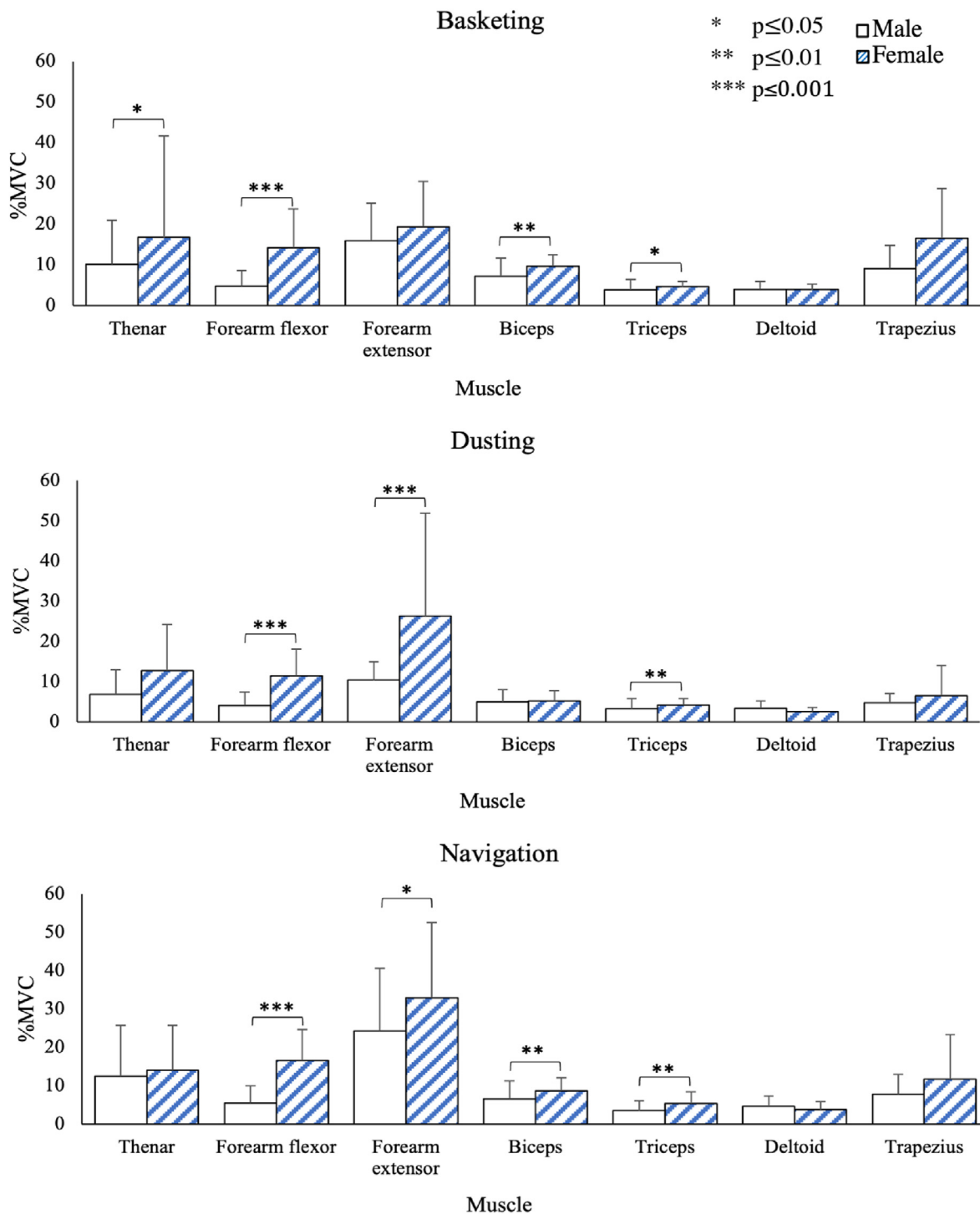


Fig. 5. %MVC in men vs. women during simulated ureteroscopy tasks (basketing, dusting, navigation).

actual physical demand, rather than a difference in perceived temporal demand or effort. This aligns with the objective %MVC results. As suggested by recent studies,¹⁰ poor ergonomic design may contribute to increased burnout and decreased career longevity in women practicing urology. Given the ongoing physician shortages²⁷ and the growing proportion of women entering the field of urology,⁴⁻⁶ it will be important to ensure that further research conducted on ergonomics in urological procedures takes into account gender differences.

Like urology, other surgical subspecialties report high rates of work-related musculoskeletal disorders, including cervical spine disease and rotator cuff pathology,²⁸ and may benefit from similar ergonomics

assessment of their equipment and operating positions. A survey of the Tennessee chapter of the American College of Surgeons found that forty percent of surgeons sustained at least one injury in the workplace, some of whom had to miss work or reduce their number of operations while recovering.²⁹ A query of several surgical subspecialties (not including urology) found similar trends of musculoskeletal discomfort across specialties, with nearly 70 percent of respondents reporting musculoskeletal pain and close to half (47.7%) stating that the pain impacted their work.³⁰ Our findings are consistent with other studies that have shown gender differences with respect to work-place injury, with female surgeons across a variety of surgical subspecialties being more likely to

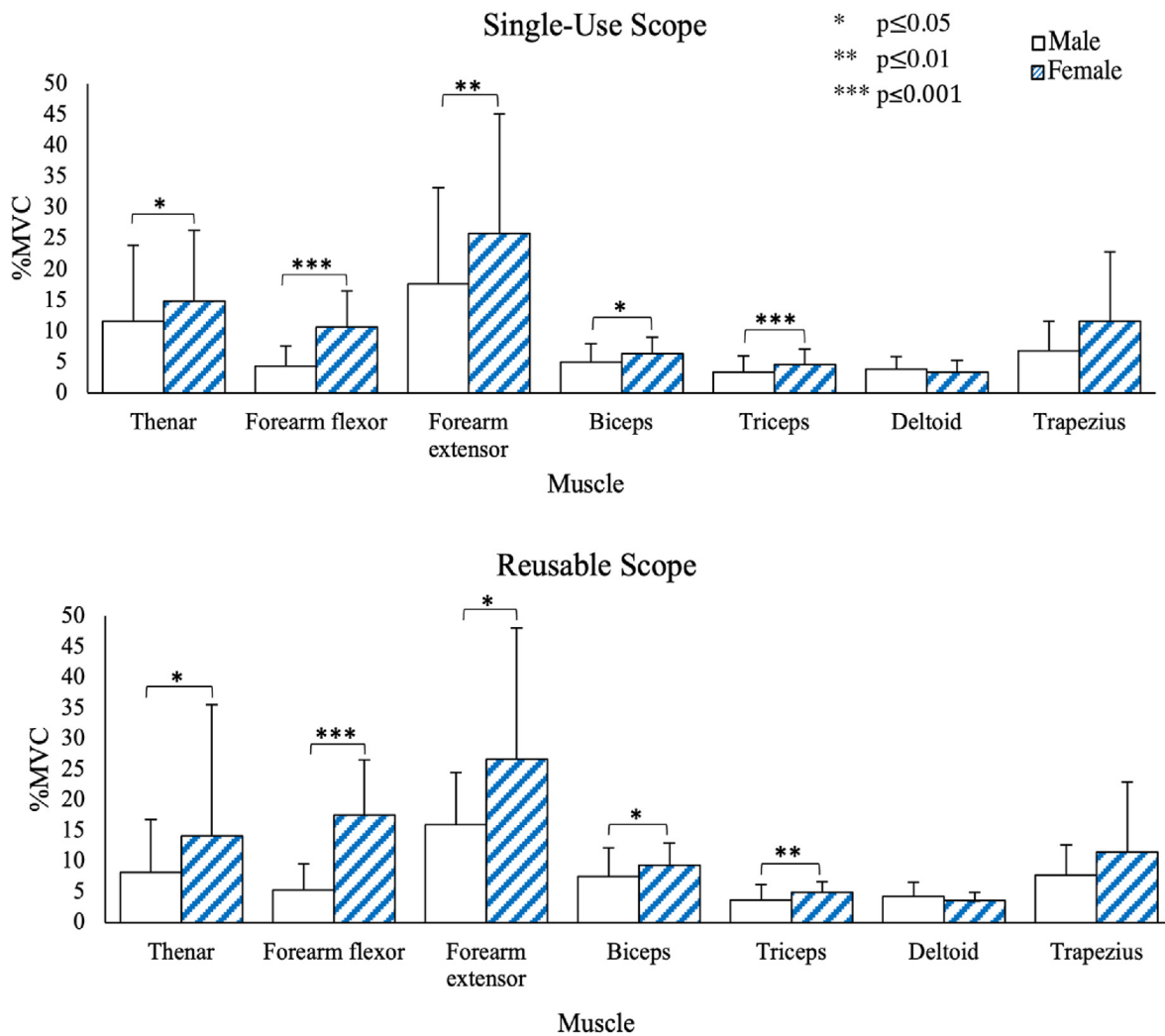


Fig. 6. %MVC in men vs women using single-use vs reusable ureteroscopes.

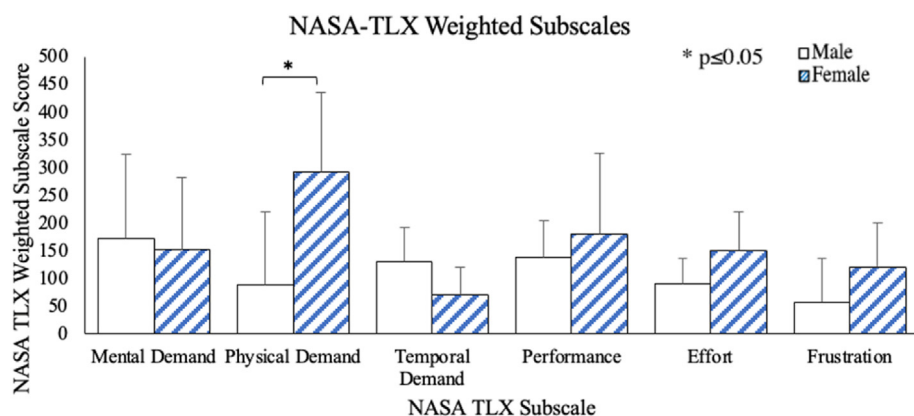


Fig. 7. NASA-TLX weighted subscales for men vs. women, averaged across all trial conditions.

report an operation-related musculoskeletal injury than male surgeons.³¹ For example, in a survey study of gastroenterologists, women reported increased endoscopy-related injuries compared to men, 63.4% vs. 40.9%, respectively ($p = 0.02$).³² Similarly, female laparoscopic surgeons were more likely to receive treatment for hand pain and were more likely to report laparoscopic staplers as being too big for their hands.³³

While it would be ideal for each surgeon to have different instruments

for optimal ergonomics, the financial aspects must be considered. Capital costs for equipment, maintenance/repair contracts, and associated support personnel are a significant part of hospital budgets and often limit equipment options. However, we hope that studies such as this can highlight the role of equipment on ergonomics and risks of work-related musculoskeletal injuries, along with potential loss of clinical productivity and negative effects on quality of life outside of work. Here, we found

that the single-use ureteroscopes typically had favorable ergonomics compared to the reusable ureteroscope, and with single-use equipment becoming cheaper and more ubiquitous in urology,³⁴ there may be an opportunity to improve ergonomics for some individuals with minimal overall financial consequences.

In order to progress towards workplace equity and to improve career longevity and productivity, future research on ergonomics and product development³⁵ should include adequate non-male participants. In addition to addressing any modifiable risk factors in the operating room which are ongoing areas of study,^{36–38} specific attention should be paid to inherent gender differences such as height, muscle mass, hand size, etc. While the American Urological Association (AUA) recognizes that gender-specific ergonomic challenges exist, the AUA recommendations on general ergonomics do not comment on the effect of specific equipment in ureteroscopy.³⁹ Areas of exploration could include optimized instrument design and customizability of operating room setup to be more inclusive of surgeons with a variety of hand sizes, heights, and strengths. This would ideally have a multifaceted approach through collaborations with surgeons, engineers, and industry. Suggestions in procedure technique or surgeon positioning should also be considered with different sized individuals in mind.

4.1. Limitations

This study has several limitations. The height of the tower with the viewing screen was not adjustable, although the heights of other room elements (table, stool) were adjustable. Of note, when told to adjust everything to their preference, the majority of participants did not ask to adjust the screen. Although the experimental rooms were set up to mimic operating room conditions as much as possible, some elements of an actual operating room were not present such as a foot pedal for a laser, a sterile gown and gloves, or live fluoroscopy that would result in side-to-side neck motion. In addition, neck extensor EMG signals were lost due to artifact. The muscles of the lower limb were not measured for the purposes of this experiment and may play a role, particularly when considering a standing vs. sitting operating position. The small sample size of our study was another limitation, including our lack of pregnant and senior surgeons, which may limit generalizability; however it is the largest to date with respect to quantified data evaluating ergonomics during kidney stone surgery. Notably, while we assessed differences between male and female surgeons, the results found here are likely

driven by biologic differences in strength, muscle mass, height, etc. which are often, but not always, correlated with gender. We would encourage further research with larger cohorts across multiple institutions, ideally during live surgery, all while maintaining adequate subject gender representation.

5. Conclusions

This study demonstrates quantitative differences between men and women in muscle activation and subjective workload during simulated ureteroscopy. Female urologists may be disproportionately affected by poor ergonomics compared to their male colleagues. This disparity should be further delineated and reduced in order to optimize career longevity, safety, and satisfaction for all urologic surgeons.

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CRediT authorship contribution statement

Erin Kim: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alec Sun:** Writing – review & editing, Software, Formal analysis. **Juan Sebastian Rodriguez-Alvarez:** Investigation, Formal analysis, Data curation. **Louisa Ho:** Writing – review & editing, Conceptualization. **Kyle O’Laughlin:** Supervision, Methodology. **Smita De:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Muscle activation by trial condition, without gender comparison (%MVC [IQR])

Task type	Basketing	Navigation	Dusting	Statistical significance (Pairwise comparisons: Basketing = B, Navigation = N, Dusting = D)
Thenar	8.1 [5.0, 12.2]	9.4 [5.1, 17.7]	5.2 [3.2, 13.2]	p = 0.03 (B vs. N) p = 0.09 (B vs. D) p < 0.001 (N vs. D)
Forearm flexor	7.2 [2.6, 11.6]	8.4 [3.1, 15.7]	5.2 [2.6, 10.6]	p = 0.002 (B vs. N) p = 0.17 (B vs. D) p < 0.001 (N vs. D)
Forearm extensor	14.4 [12.2, 18.2]	22.9 [17.3, 30.6]	12.8 [9.5, 15.8]	p < 0.001 (B vs. N) p = 0.21 (B vs. D) p < 0.001 (N vs. D)
Biceps	8.4 [5.2, 10.8]	6.8 [4.7, 9.6]	4.7 [2.8, 6.7]	p = 0.09 (B vs. N) p < 0.001 (B vs. D) p < 0.001 (N vs. D)
Triceps	3.8 [2.0, 5.6]	3.5 [1.9, 5.8]	3.1 [1.8, 4.6]	p = 0.86 (B vs. N) p < 0.001 (B vs. D) p < 0.001 (N vs. D)
Deltoid	3.5 [2.7, 4.7]	3.8 [2.5, 5.5]	2.6 [1.9, 3.3]	p = 0.07 (B vs. N) p < 0.001 (B vs. D) p < 0.001 (N vs. D)
Trapezius	8.1 [5.4, 18.4]	6.4 [3.9, 10.9]	3.9 [2.7, 6.4]	p < 0.001 (B vs. N) p < 0.001 (B vs. D) p < 0.001 (N vs. D)

Ureteroscope type			
	Single-use	Reusable	Statistical significance
Thenar	9.6 [4.7, 14.8]	6.3 [3.7, 11.1]	p < 0.001
Forearm flexor	4.9 [2.5, 10.5]	8.8 [3.1, 15.2]	p < 0.001
Forearm extensor	16.0 [12.2, 23.1]	16.0 [12.1, 22.8]	p = 0.17
Biceps	5.2 [3.1, 7.7]	8.1 [5.0, 11.3]	p = 0.001
Triceps	3.2 [1.9, 5.4]	3.8 [2.0, 5.3]	p = 0.001
Deltoid	3.0 [2.5, 4.8]	3.3 [2.5, 4.7]	p = 0.001
Trapezius	5.7 [3.9, 9.8]	6.5 [3.9, 10.4]	p = 0.09
Surgeon position			
	Sitting	Standing	Statistical significance
Thenar	6.7 [4.5, 12.3]	8.5 [3.9, 14.6]	p = 0.15
Forearm flexor	6.7 [2.9, 11.7]	6.8 [2.7, 12.7]	p = 0.73
Forearm extensor	16.3 [12.8, 22.5]	15.8 [11.8, 24.4]	p = 0.26
Biceps	6.2 [3.7, 9.3]	6.3 [4.0, 9.3]	p = 0.09
Triceps	3.5 [1.9, 5.3]	3.5 [2.1, 5.4]	p = 0.45
Deltoid	3.3 [2.6, 5.3]	3.0 [2.1, 4.2]	p = 0.01
Trapezius	6.6 [3.9, 11.2]	5.5 [3.6, 9.1]	p = 0.002

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