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Ergonomics in the OR: An Electromyographic Evaluation of Common Muscle Groups Used During Simulated Flexible Ureteroscopy – a Pilot Study

Henry C. Wright, George Gheordunescu, Kyle O'Laughlin, Alec Sun, Juan Fulla, Naveen Kachroo, and Smita De

OBJECTIVE To assess the effects of different surgeon positions and ureteroscope types on muscle activation as measured by surface electromyography (sEMG) during simulated ureteroscopy in an endourology box-trainer model and the kidney phantom.

METHODS For this exploratory study, sEMG was used to quantify muscle activation of 3 endourology fellows during various ureteroscopic tasks. Electrodes were placed on the ureteroscope-holding side of the following muscles: thenar, forearm flexor, forearm extensor, biceps, triceps, deltoid, and trapezius. Subjects wore fitted lead aprons in an operating room and used a cystoscopy table with surgical drapes and an endoscopic video tower. Trials were completed with a disposable and reusable ureteroscope, both in the standing and sitting positions. Each subject performed an identical set of tasks in a phantom silicone kidney and ureteroscopy box trainer to recreate the procedural components of basketing, navigating a renal collecting system, and dusting. Raw EMG data for each task was processed and normalized as a percent of each subject's maximum voluntary contraction to allow comparison.

RESULTS The forearm extensor was the most heavily utilized muscle. The trapezius and deltoid muscles were activated more during sitting whereas the forearm flexors had increased activity during standing. The heavier reusable ureteroscope had increased forearm extensor activation compared to the disposable ureteroscope.

CONCLUSION Preliminary data show measurable differences in muscle activation based on both surgical posture and type of ureteroscope used. This highlights the need for more extensive EMG studies to identify techniques and equipment to optimize ergonomics and potentially minimize injury during flexible ureteroscopy. UROLOGY 170: 66–72, 2022.

The rising prevalence of nephrolithiasis coupled with advancements in endoscopic and laser technologies have resulted in an exponential rise in utilization of ureteroscopy (URS), now the most commonly employed treatment modality for stones in the United States.[1,2] This increased adoption however is not without consequence; over 60% of endourologists have experienced orthopedic complaints directly correlated with annual ureteroscopic caseload.[3] The morbidity of this is emphasized by a recent survey of surgeons with musculoskeletal disorders and complaints in which 37.5% indicated they were using medication and/or therapy at the time to reduce symptoms, while 26.7% had required work leave, and 40% had to make intraoperative adjustments.[4,5] Poor operative ergonomics may significantly contribute to this worrying trend and a lack of knowledge about optimal body posture and equipment is frequently cited by urologists, in part related to the paucity of literature on ergonomics, especially in flexible URS.[6]

The American Urological Association (AUA) recently published a White Paper with an entire section dedicated to surgeon ergonomics.[7] However, most of the recommendations were adapted from the laparoscopic and the

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robotic literature, which mainly consists of survey studies though some have used electromyography (EMG) to objectively assess muscle activation as an indicator of ergonomics.[8-12] A recent review demonstrated a lack of formal guidelines for ergonomics in ureteroscopy and a need for further evaluation.[13] To our knowledge, no studies to date have quantified the effects of different surgeon positions on ergonomics during ureteroscopy.

The aim of this pilot study was to investigate if there are measurable differences in muscle activation during routine steps of flexible ureteroscopy in a simulated operating room setting. We sought to assess the effects of different ureteroscope types (disposable vs reusable) and surgeon positions (sitting vs standing).

METHODS

Following institutional review board approval at our academic institution, 3 endourology fellows were recruited and provided informed consent to participate in the study. Briefly, surface EMG data were collected during 3 simulated flexible ureteroscopy tasks (basketing, navigation, and dusting) in different surgeon positions (sitting vs standing) and with different ureteroscope types (disposable vs reusable). Tasks were completed in identical order for each trial. Each subject performed trials for each combination of variables in a randomized order. Trials were performed in sets of two with 10 minutes break between trials within the set and a one hour break between the sets to allow recovery and minimize effect of carryover fatigue (Supplemental Figure 1).

Ureteroscopy Set-up

Trials were performed in a standard operating room suite. The operating room table was equipped with Yellofin (Hillrom, Chicago, IL) stirrups and covered with standard lithotomy surgical drapes. The operating table was placed at the surgeons' preferred height. Subjects wore their personal fitted lead aprons. Stools (for the sitting trial) were adjusted to the user's preferred height. The endoscopic video tower screen (Karl Storz SE & Co. KG, Tuttlingen, Germany) was set to a standard position to the side of the "patient's" torso to allow for fluoroscopy equipment and as close to eye level as possible but without interference from the drapes. A phantom silicone kidney with ureter (Simagine Health Inc., Seattle, WA) and ureteroscopy box trainer (Cook Medical LLC, Bloomington, IN) were used as the models for the study.

Each trial consisted of 3 specific tasks designed to recreate the procedural components of basketing, navigating a renal collecting system, and dusting kidney stones. For basketing, we used a phantom silicone kidney and ureter with a ureteral sheath (Boston Scientific, Marlborough, MA) in place. The ureteroscope was advanced through the ureter, into a calyx, touched to an embedded stone, and then withdrawn out of the sheath. Four "stones" were basketed from each of the 5 calyces for a total of 20 'basketing' movements. Navigation involved ureteroscope insertion, ureter evaluation, and sequential inspection of several "kidney chambers" in the box trainer to mimic complex pyeloscopy. Finally, subjects simulated dusting by moving the ureteroscope with a 200 micron laser fiber continuously over a 1 cm "stone" marked inside a calyx of the box trainer for a total of 2 minutes. There were no rest breaks between tasks within a trial.

A Flex X^2 (Karl Storz, Tuttlingen, Germany) reusable flexible ureteroscope with a P3-3 pendulum off-set camera (Karl Storz, Tuttlingen, Germany) and a PU3022 disposable ureteroscope with accompanying monitor (Pusen Medical, Zhuhai,China) were used. Both ureteroscopes utilize intuitive tip deflection. The Flex X^2 weighs 339 grams and the P3-3 camera head weighs 226 grams. The PU3022 weighs 91 grams.

EMG

Surface EMG data were collected using AD Instrument's PowerLab 8/35, Octal Bio Amp data acquisition hardware, and Labchart 8 software (AD Instruments, Colorado Springs, CO). Skin overlying the muscles of interest (Fig. 1) was prepped with 70% isopropyl alcohol pads. Disposable silver-silver chloride EMG sticker electrodes (MLA1010B, AD Instruments, Colorado Springs, CO) were placed in a standard bipolar configuration parallel to the muscle fibers over the following muscle groups of the surgeon's preferred ureteroscope-driving side: thenar, forearm flexor, forearm extensor, biceps, triceps, trapezius, and neck extensor muscles according to SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) guidelines.[14] No electrodes were placed on the non-ureteroscope-holding side due to the limited number of channels available on the data acquisition hardware.

A ground electrode was placed on the right lateral epicondyle. Electrode leads were secured to the skin using tape to minimize motion artifact. The mean of 3 maximum voluntary contractions (MVC) of each muscle was obtained prior to wearing lead aprons.[15] Raw EMG signals were recorded with a sampling rate of 4000 Hz and processed with a high pass filter of 10 Hz. The filtered EMG was then full-wave rectified by taking the absolute value and then smoothed using the square root calculation to give the root-mean-square (RMS) EMG. The RMS EMG was normalized to the mean MVC for each subject and presented as %MVC for data analysis.

Analysis and Statistics

Median %MVC and IQR were calculated by aggregating each of the three surgeons' trials under the various trial conditions. Data from all subjects were grouped in multiple ways: surgical position, ureteroscope type, and task. While there was no a priori power calculation, for the purposes of an exploratory analysis, Wilcoxon signed-rank tests were used to compare the postures and ureteroscope types. The trial conditions were basketing and navigation while standing with a disposable ureteroscope. All %MVC data were collected and analyzed in R Studio 1.4.1103. All figures were created with the ggplot2 package.

RESULTS

All 3 subjects were male endourology fellows. Additional demographic information including height, weight, glove size, and experience level is in the supplemental files (Supplemental Table 1). EMG data were successfully collected in all subjects across all tasks and muscles except for the neck extensor muscle. The electrodes placed on the neck extensor did not record measurable activity above the background noise. The deltoid muscle EMG recording in one of the trials of one subject was excluded due to motion artifact. The average time to completion was 256.86 seconds, 56.11 seconds, and 120 seconds for the basketing, navigation, and dusting tasks, respectively.

Figure 1. EMG electrode placement (top row): (**A**) neck extensor, (**B**) trapezius, (**C**) deltoid, (**D**) triceps, (**E**) biceps, (**F**) ground electrode on lateral epicondyle, (**G**) forearm extensor, (**H**) forearm flexor, (**I**) thenar. Operating room suite setup (bottom). (Color version available online.)

The forearm extensor was the most heavily recruited muscle across all tasks and variables (Table 1). As seen in Figure 2, there was a notable increase in forearm extensor activation with the reusable ureteroscope compared to the disposable ureteroscope across all tasks (22.9 vs 13.5 %MVC, respectively) (P = .001). Forearm flexors (P = .014), biceps (P = .043), and trapezius (P = .027) also had higher % MVC with the reusable ureteroscope.

Increases in muscle activation with sitting compared to standing were seen in the trapezius (10.2 vs 6.2 %MVC) (P = .021) and deltoid (4.0 vs 2.1 %MVC) (P = .002) muscles (Table 1, Fig. 2). Forearm extensors were also more heavily activated in the sitting position, but this was not significant. On the contrary, forearm flexor activation was greater while standing (8.6 vs 5.3 %MVC) (P = .002).

In terms of differences by task, as noted in Table 1 and Figure 3, the forearm extensors and trapezius were the most used muscles in the basketing task, while the predominant muscle groups during dusting included both of these along with the, thenar and forearm flexors. The least used muscles were the biceps, triceps, and deltoid during all tasks (Fig. 3), though all three were most heavily activated during basketing.

DISCUSSION

Previously relegated to a secondary concern, there is now increasing awareness of the importance of ergonomics as related to musculoskeletal injuries faced by surgeons as evidenced by the plethora of scientific and popular press articles published on the topic in the last few years.[4,5,9,13,16-21]

Unfortunately, minimal work has been done addressing the distinctive ergonomic challenges for endourologists who wear a full lead apron and watch a screen often positioned obliquely, rather than directly in front of the eyes, due to obstructive elements like fluoroscopy equipment. Only one small study to date has used surface EMG to measure muscle activation during ureteroscopy[19] with different ureteroscope types, but was limited by inclusion of only 1 surgeon and lack of a realistic operating room setup.

Our pilot study evaluating EMG activity during simulated ureteroscopy is, to our knowledge, the largest and most comprehensive to date. This data demonstrate that there are measurable differences in muscle activation between

Table 1. EMG muscle data.

EMG Muscle Data Across All Tasks

	Thenar	Forearm Flexor	Forearm Extensor	Biceps	Triceps	Deltoid	Trapezius
All data (n = 34*/36)	9.4 [6.8, 11.0]	8.1 [4.5, 11.4]	17.9 [10.9, 28.0]	5.8 [3.6, 7.8]	3.0 [2.5, 5.0]	2.8 [1.3,4.9]	7.2 [3.9, 10.9]
Sitting (n = 18)	9.0 [6.4, 10.6]	5.3 [4.2, 10.0]	20.3 [10.5, 27.8]	6.0 [4.5, 7.9]	3.0 [2.5, 4.5]	4.0 [2.2, 7.5]	10.2 [3.8, 18.4]
Standing (n=16*/18)	9.6 [7.1, 11.2]	8.6 [8.1, 12.7]	15.0 [11.4, 27.0]	5.2 [3.5, 6.9]	3.0 [2.6, 5.9]	2.1 [1.3, 3.2]	6.2 [4.2, 8.3]
Disposable Scope (n=16*/18)	8.6 [6.8, 9.9]	6.1 [4.4, 8.6]	13.5 [9.5, 24.7]	4.9 [3.0, 6.9]	2.89 [2.2, 6.9]	2.8 [1.2, 5.6]	6.3 [3.9, 9.6]
Reusable Scope (n=18)	9.9 [7.1, 11.4]	9.4 [7.4, 13.0]	22.9 [13.9, 35.5]	6.4 [4.1, 8.6]	3.1 [2.6, 4.6]	3.0 [1.5, 4.9]	8.3 [4.2, 11.5]

EMG Muscle Data Between Tasks

	Thenar	Forearm Flexor	Forearm Extensor	Biceps	Triceps	Deltoid	Trapezius
Basketing (n = 11*/12)	9.4 [7.2, 10.8]	8.3 [4.5, 11.3]	18.1 [13.9, 25.8]	7.4 [6.0,8.8]	4.7 [3.5, 8.4]	3.3 [2.7, 7.4]	10.2 [8.3, 22.8]
Navigation (n = 11*/12)	9.5 [8.2, 12.2]	8.1 [6.2, 11.4]	22.9 [10.3, 30.0]	6.0 [4.3, 7.0]	3.1 [2.6, 5.8]	2.2 [1.2, 4.8]	8.3 [5.9, 12.9]
Dusting (n = 12)	8.6 [5.1, 10.4]	6.3 [4.0, 11.2]	13.1 [7.8, 25.1]	3.3 [1.4, 4.4]	2.4 [2.0, 2.6]	2.1 [0.8, 3.4]	3.0 [2.0, 3.7]

reported as %MVC median [IQR].
* = deltoid muscle sample size. Basketing and navigation while standing using the disposable scope excluded due to artifact in one trial.

ureteroscope types, surgeon positions, and tasks. In addition, we were able to differentiate the activation levels between muscles for the various tasks and variables as well as identify muscles that were not being used. With respect to position, there has been some indication that sitting may be preferable[13,22,23]; however, these findings are based mainly on subjective comments or questionnaires. Our study suggests that the issue may be more complex as we found that while the forearm flexors had increased activation while standing, sitting required *increased* work of the deltoid and trapezius muscles. This may be related in part to the particular task. For example, basketing involves more motion of the upper arm and shoulder while dusting requires fine movement of the hand and wrist with the upper arm and torso relatively stationary. This is reflected in the data, which showed that the thenar and forearm muscles were activated more than the upper arm or shoulder muscles during the dusting task. The variation in effect of both position and task on muscle activation can have implications for surgeons who prefer one lasering method over the other.

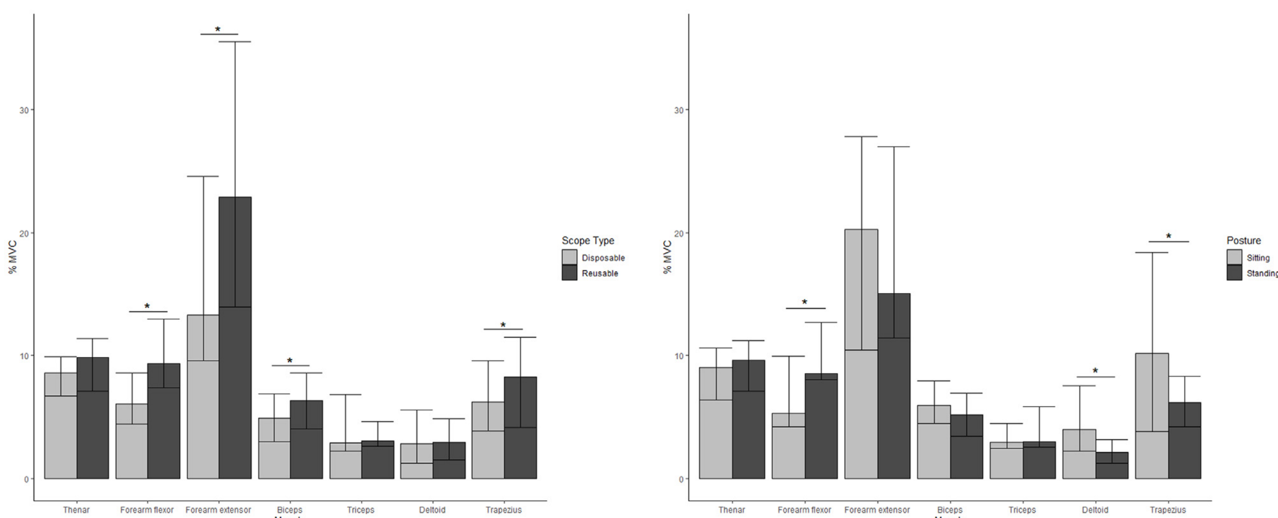

Figure 2. Median %MVC of each muscle across all tasks, when using disposable or reusable ureteroscopes (left). Median %MVC of each muscle across all tasks, when sitting or standing (right). Bars represent interquartile range (IQR). * = Statistical significance (*P* <.05). MVC = Maximum voluntary contraction.

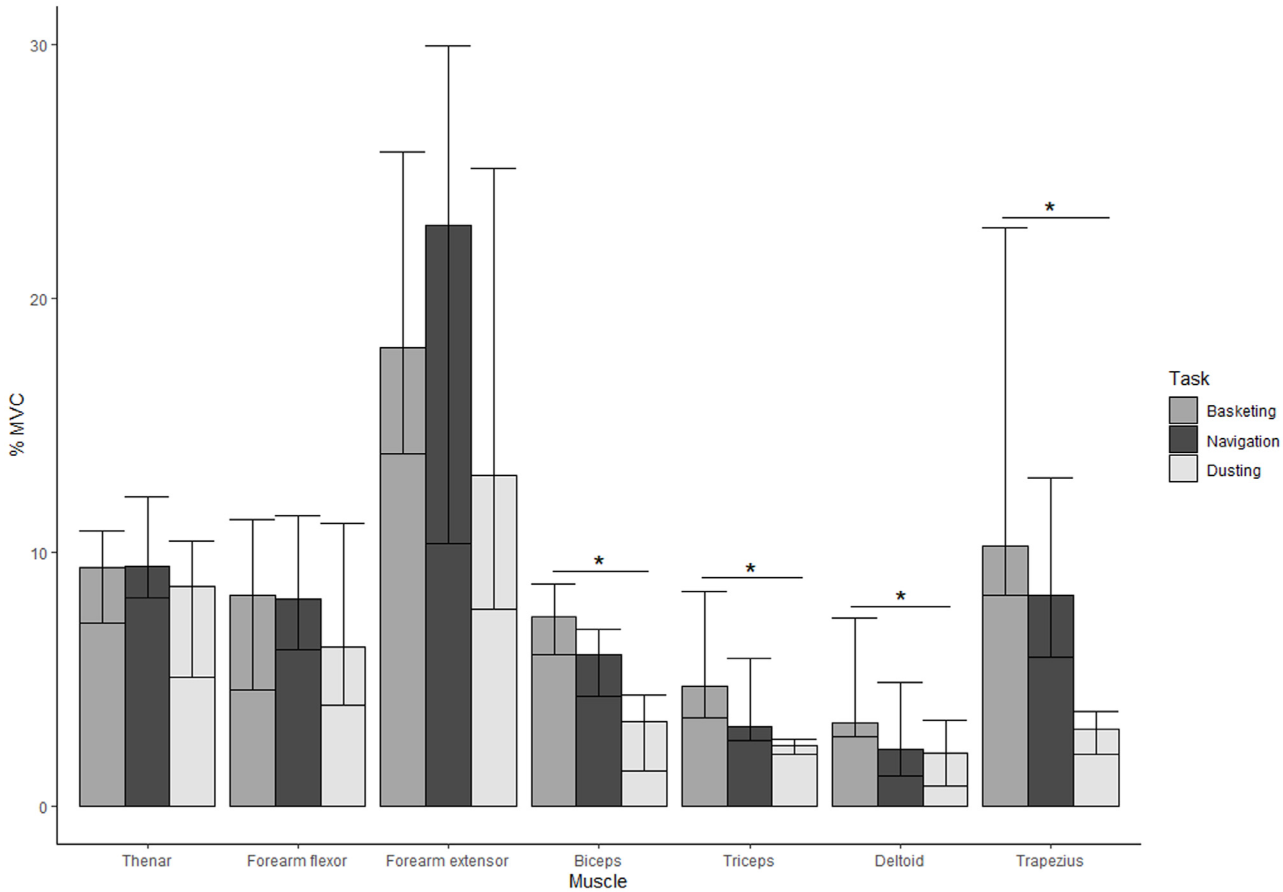

Figure 3. Median %MVC of each muscle, grouped by task. Bars represent IQR. * = Pairwise statistical significance (*P* <.05) between tasks. MVC = Maximum voluntary contraction.

Not surprisingly, and also consistent with the prior study by Ludwig et al, the lighter disposable ureteroscope tended to have lower levels of muscle activation.[19] However, different ureteroscopes were used for each study and there has not been a direct comparison between various disposable ureteroscopes, each of which have unique features that might affect their ergonomics (ie Bard Wiscope with self-locking deflection, Boston Scientific Lithovue with EmpowerTM for self-basketing). The self-locking feature noted above is of particular interest as tip deflection may also have ergonomic implications as surgeons who prefer counterintuitive ureteroscope deflection are twice as likely to have hand/wrist problems.[24]

Of note in our study, we focused on the ureteroscope-driving upper extremity as the hand, elbow, and shoulder are common regions for musculoskeletal complaints among endoscopists.[21,24] However, other muscle groups, particularly the neck and back, should be included in future studies as chairs with back support and arm rests as well as table optimization have been shown to reduce postural stress and discomfort.[16,25]

We chose to use wired EMG in order to incorporate the effect of lead aprons, and were concerned about signal interference and proper fit of the vests over wireless EMG leads which have been used in other studies. Also, wired leads are flat while wireless ones protrude significantly from the skin surface, making use with lead aprons challenging. Of note, the Ludwig study, which utilized wireless leads, did not evaluate the trapezius muscle, the second most activated muscle during basketing.

As noted in the recent review by Ong eg al,[13] robotic-assisted flexible URS has the potential to eliminate the ergonomic issues of classic flexible URS. Recently published data suggest that the Roboflex Avicenna provides similar operative outcomes to flexible URS.[26] Data from the IDEAL stage 1 and 2 trials using a validated questionnaire demonstrated improvement in pain, stiffness, and numbness measures with the Roboflex Avicenna device compared to standard flexible URS.[27] With the robotic system, the surgeon can sit comfortably without a lead apron at a console behind a radiation shield. Furthermore, alternative radiation barriers such as overhead suspended shields,[28] or fluoroscopy-free surgery need to be further explored in urology, with the goal of eliminating the need for heavy lead vests that contribute to many musculoskeletal issues for proceduralists.[29]

While this is a pilot study inherently limited by a small sample size, there are other limitations. The purpose of this pilot study was to study degree of muscle activation during the different surgeon positions and tasks to inform future research, but this design did not allow us to analyze the muscle fatigue. Future studies with a larger sample size should be optimized with longer trials and/or higher %MVC tasks to allow for accurate fatigue analysis of the EMG signal to be performed.[30] In addition, all subjects were male endourology fellows of similar experience level. Larger studies with diverse subjects are needed to evaluate for statistical significance and applicability of these findings to a broader population. Leisure time activity scales to evaluate the effects of physical activity may also be helpful. Furthermore, the study was performed on trainer models. While simulated tasks were shorter in duration than actual ureteroscopic procedures for nephrolithiasis, they are consistent with simulated ureteroscopy trials in the literature.[19] Future surgeon-specific variables to study include gender, age, height, hand size, hand dominance, type and frequency of physical activity, and experience level. Modifiable variables that could be optimized include surgical time of day, lead gowns (one versus two-piece), tip deflection, and models of ureteroscopes. As noted, muscle groups such as the erector spinae, a neck extensor, and lower extremity muscles are also of interest yet were not evaluated here. Despite these limitations, this study provides the first objective data evaluating ergonomics for different positions in flexible ureteroscopy.

CONCLUSIONS

EMG can be successfully used to quantify muscle activation during simulated URS. Preliminary data suggest that there are measurable differences in muscle activation based on the type of ureteroscope used, surgical posture, and task. Given the high rates of pain and orthopedic complications suffered by surgeons, larger and more extensive studies are needed to identify techniques and equipment to optimize operating room ergonomics.

AUTHORS' CONTRIBUTION

Wright: study design, data acquisition, manuscript drafting, editing and review

GG: study design, literature search, data acquisition, data analysis, manuscript drafting, editing and review; **KO'L:** study design, data analysis, manuscript editing and review; **AS**: data analysis, manuscript drafting, editing and review; **JF**: study design, data acquisition, manuscript review; **NK**: study design, data acquisition, manuscript editing and review; **SD**: concept, study design, literature search, data analysis, manuscript drafting, editing and review

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SUPPLEMENTARY MATERIALS

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