Factors affecting holmium laser inefficiency: Comparison of laryngeal mask airway and endotracheal tube use during flexible ureteroscopy for renal stones

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Introduction

Flexible ureteroscopy with laser lithotripsy (fURSL) has become the standard treatment option for kidney stones of various sizes, locations, and compositions.[1] Despite recent advancements to improve fURSL, many inefficiencies exist that can potentially increase operative time and therefore increase risk of complications such as ureteral damage, bleeding, and urosepsis.[2,3]

During surgery, respiratory motion causes clinically significant movement of the kidneys which can defocus laser energy from the stone and require the surgeon to halt laser firing; the kidney has been reported to move 8.1 ± 4.33 mm in the superior-inferior direction[4]. Patient breathing may be influenced by factors such as BMI and airway securement by endotracheal tube (ETT) or laryngeal mask airway (LMA). Currently, there is no widely accepted guideline for choosing a method of airway securement for fURSL and this is mainly decided by the surgeon, anesthesiologist, and/or institutional preference.

Release of the Lumenis P120H holmium laser provides access to intraoperative data recorded within the system previously unavailable with older holmium systems. In addition to providing information such as total lasing time and energy used, newer P120H laser systems record the timestamps and duration of each laser activation for every case. This allows for calculation of the duration of pauses between laser firings which can be used to calculate a “lasing inefficiency” percentage for every case that is adjusted for total lasing time. This may be influenced by factors such as time needed for navigation to another site and stone manipulation but also by potentially modifiable factors such as kidney movement caused by respiratory motion.

To our knowledge, there have been no previous studies investigating the duration of pauses between laser use utilizing data from newer P120H laser systems. Here, we aimed to investigate factors associated with longer pauses between laser pulses which may increase total intraoperative time. We hypothesized that ETT intubation decreases lasing inefficiency which may be exaggerated with increased stone burden and/or patient BMI.

Methods

Patients undergoing fURSL from an ongoing clinical trial at Vanderbilt University Medical Center (VUMC) comparing ureteroscopic treatment of kidney stones with and without the use of Moses technology were included (NCT04505956). Ureteroscopy was solely performed by an attending endourologist. The dataset from the trial includes detailed and reliable metrics such as patient demographics (i.e., age, sex, race, and BMI), operative parameters (i.e., total operative time, ureteral access sheath time, lasing time, and total laser energy used), as well as stone characteristics (i.e., number of stones, stone density, and stone location within the urinary tract).

Lasing Inefficiency Calculations Per Each Case

Output logs were exported from the Lumenis P120H laser system into Excel format which contains detailed timestamps indicating the start of laser activation and duration of laser firing for every laser initiation in each surgical case. Utilizing the start time and duration of laser firing, the end timestamp of each laser activation was calculated. Subtracting the start timepoint of the next lasing pulse from the end timepoint of the previous pulse yielded the **pause time** between pulses. The pause time between every activation in each case was then added to yield the **total pause time**. The **total lasing time** was calculated by subtracting the ending timepoint of the last laser pulse from the starting timepoint of the first laser pulse. Finally, the **lasing inefficiency (%)** of the case was calculated by dividing the total pause time by the total lasing time which is done to adjust the total pause time for the length of the case. A sample laser log and listed calculations are shown below in Figure 1.

Included in original laser log output

Calculated for each lasing timestamp

12:49:52	Urology	Moses 200 DFL						**Lasing Start**	**Energy (kJ)**	**Lasing Duration (sec)**	**Lasing End**	**Pause Time**
			Off	Left	0.2	80	Low	12:49:52 PM	0.2294	0:00:15	12:50:07 PM	-
			Off	Left	0.2	90	Low	12:50:32 PM	0.7176	0:00:42	12:51:14 PM	0:00:25
			Off	Right	0.3	120	Low	12:51:14 PM	1.3722	0:00:39	12:51:53 PM	0:00:00
			Off	Right	0.3	120	Low	12:51:54 PM	0.0258	0:00:02	12:51:56 PM	0:00:01
			Off	Left	0.2	90	Low	12:52:57 PM	0.0264	0:00:03	12:53:00 PM	0:01:01
			Off	Left	0.2	90	Low	12:54:36 PM	0.1204	0:00:08	12:54:44 PM	0:01:36
			Off	Right	0.3	120	Low	12:54:44 PM	0.099	0:00:04	12:54:48 PM	0:00:00
			Off	Left	0.3	90	Low	12:54:56 PM	10.5456	0:06:36	1:01:32 PM	0:00:08
			Off	Right	0.3	120	Low	1:01:33 PM	0.459	0:00:14	1:01:47 PM	0:00:01
			Off	Right	0.3	120	Low	1:01:47 PM	0.0684	0:00:02	1:01:49 PM	0:00:00
			Off	Left	0.3	90	Low	1:01:52 PM	0.0582	0:00:02	1:01:54 PM	0:00:03
			Off	Left	0.3	90	Low	1:01:57 PM	0.0126	0:00:01	1:01:58 PM	0:00:03
											Total Pause Time =	0:03:18
											Total Lasing Time (Last Lasing End - First Lasing Start)	0:12:06
											Lasing Inefficiency (Total Pause Time/Total Lasing Time)	27.27%

Figure 1. Sample laser log demonstrating original output provided by Lumenis P120H laser system as well as calculations of total pause time, total lasing time, and lasing inefficiency (%).

Lasing Pause Time Cutoff Calculation

One aspect of the lasing inefficiency calculation that was not immediately evident was a large discrepancy in pause times between laser firings in some of the cases. These cases contained outliers: long lasing pause times that were a few minutes long between laser activations, likely caused by a switch from lasering to basketing stones or a movement to different location within the kidney or urinary tract. Thus, if these outliers were included, this would create a bias in these cases to disproportionately higher lasing inefficiency. We sought to determine a cutoff point for the pause times included in laser inefficiency calculation at which we could reasonably say that immediate stone lasering was not occurring due to an instrument change or movement to another location.

The lasing pause times for every case were included in a histogram to determine the spread of data (Fig. 2). There were 5,156 individual data points with a median value of 1 second, IQR of 1 - 3 seconds, and range of 0 - 1078 seconds. Since there is very little precedent in the literature for statistically determining a cutoff value to exclude outliers in a dataset like this, an initial cutoff value at the 95th percentile was chosen which was at 12 seconds. However, we only wished to exclude major outliers, and moved this cutoff value to 30 seconds which is approximately at the 98.5th percentile. The total pause time for each case log was modified to exclude any pause times greater than or equal to 30 seconds. Anecdotally, this amount of time can capture the time required for anesthesia personnel to deepen the patient or (re)administer paralytic agent.

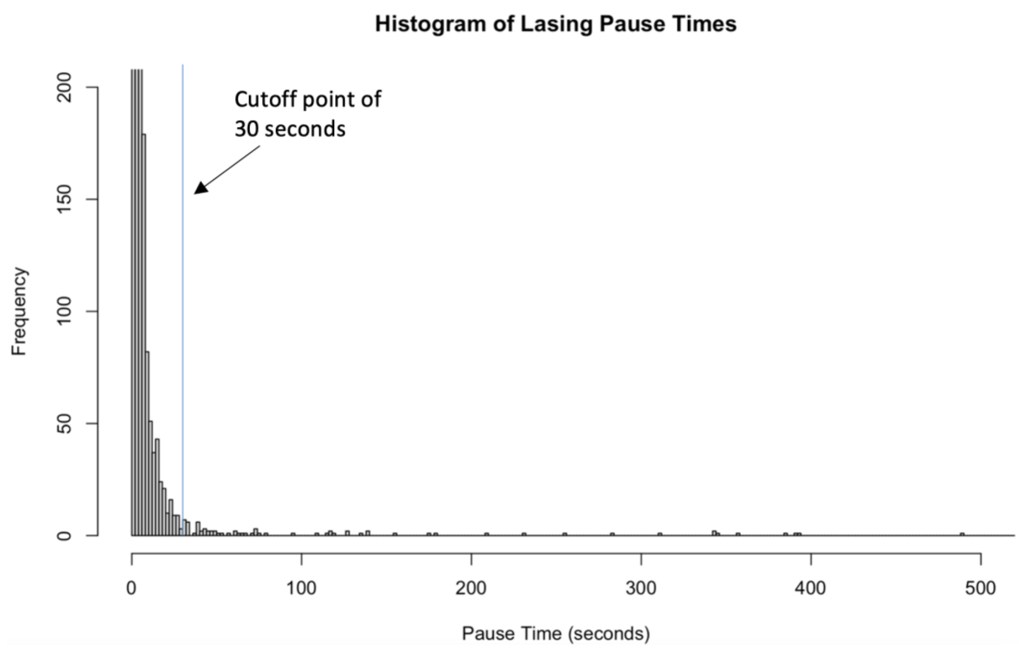


Figure 2. Histogram of lasing pause times and final cutoff value at 30 seconds.

Data Extraction and Variables

Patient cases were only included in this study if they had a complete laser output log associated with the surgery, patient demographic and anthropometric data, and intraoperative metrics. At the time of writing, there were 63 patient cases available, but only 48 of these had full sets of data for analysis and thus were included. For each case, the total pause time, total lasing time, and lasing inefficiency were calculated as shown above (Fig. 1) and recorded. Using deidentified clinical trial data, the following variables were recorded for each patient:

Age, sex, race, ASA class, BMI, stone density in Hounsfield Units (HU), number of stones, total laser energy (kJ), method used to secure patient airway by anesthesia team (LMA or ETT), placement of stent or nephrostomy tube prior to surgery, stone location within the urinary tract (i.e. renal pelvis, upper pole, lower pole, UPJ, etc.), use of a ureteral access sheath during the surgery (UAS), lasing mode (Moses or Standard), and axial stone size category.

Statistical Analysis

For univariate analysis, the percentage lasing inefficiency was compared utilizing a Linear Regression for continuous variables, a two-tailed Mann Whitney U test for categorical variables with two groups, and a Kruskal-Wallis one-way analysis of variance for categorical variables with more than two groups. A one-tailed Mann Whitney U test was used to compare lasing inefficiency for ETT vs LMA since the original hypothesis predicted ETT to have lower lasing inefficiency than LMA. A multivariate linear regression was performed to compare lasing inefficiency with multiple variables measuring anesthesia administration and stone burden (number of stones and stone size).

Results

Table 1. Patient demographics, operative parameters, and stone characteristics for all included cases

Variables	Median or Total (N)	IQR or Percentage (%)
Age	59.0	51.75 - 67.50
Sex		
Female	26	54.2%
Male	22	45.8%
Race		
Caucasian	45	93.8%
African American	2	4.2%
Asian	1	2.1%
BMI	31.02	26.82 - 37.98
ASA Classification		
1	4	8.3%
2	17	35.4%
3	25	52.1%
4	2	4.2%
Anesthesia		
LMA	30	62.5%
ETT	18	37.5%
Stone Density (HU)	1207.0	896.2 - 1392.8
Number of Stones	1.0	1.0 - 2.0
Total Axial Stone Size Category (mm)		
8.0-12.0	18	37.5%
12.1-16.0	18	37.5%
16.1-20.0	12	25%
Pre-op Stent or Nephrostomy Present		
Stent	13	27.1%
Nephrostomy	0	0%
None	35	72.9%
Hydronephrosis Present		
Yes	31	64.6%
No	17	35.4%
Stone Location		
Renal Pelvis	13	27.1%
Upper Pole	1	2.1%
Interpolar	0	0%
Lower Pole	13	27.1%
Calyceal Diverticulum	0	0%
Proximal Ureter/UPJ	4	8.3%

Multiple locations	17	35.4%
Use of UAS		
Yes	45	93.8%
No	3	6.3%
UAS Time (minutes)	25.0	21.0 - 34.0
Lasing Mode		
Moses	24	50%
Standard	24	50%
Lasing Time (minutes)	15.7	11.1 - 24.8
Operative Time (minutes)	35.0	30.0 - 43.0
Total Lasing Energy (kJ)	12.18	8.18 - 17.96
Total Patients	48	

UAS – ureteral access sheath, HU – Hounsfield units, LMA – laryngeal mask airway, ETT – endotracheal tube, UPJ – ureteropelvic junction

Table 2. Univariate Analysis of Lasing Inefficiency Compared to Study Variables

Variables	Average Lasing Inefficiency (%)	p-value
Age	-	0.563[1]
Sex		0.719[2]
Female	24.41	
Male	24.24	
Race		†
Caucasian	24.57	
African American	19.67	
Asian	22.67	
BMI	-	0.113[1]
ASA Classification		†
1	23.24	
2	26.35	
3	23.15	
4	24.06	
Anesthesia		**0.0212**[3]
LMA	26.50	
ETT	20.70	
Stone Density (HU)	-	0.862[1]
Number of Stones	-	0.699[1]
Total Axial Stone Size Category (mm)		0.552[4]
8.0-12.0	25.16	
12.1-16.0	24.16	
16.1-20.0	23.34	
Pre-op Stent or Nephrostomy Present		0.508[4]
Stent	25.02	
Nephrostomy	-	
None	24.07	
Stone Location		†
Renal Pelvis	24.16	
Upper Pole	21.44	
Lower Pole	23.56	
Proximal Ureter/UPJ	30.83	
Multiple locations	23.69	
Use of UAS		†
Yes	24.00	
No	29.22	
Lasing Mode		0.631[2]

Moses	23.80	
Standard	24.85	
Total Lasing Energy (kJ)	-	0.493[1]
Overall	24.33	

[1]Linear Regression
[2]Two-Tailed Mann Whitney U
[3]One-Tailed Mann Whitney U
[4]Kruskal–Wallis one-way analysis of variance
[†]Not enough samples in each group to accurately perform statistical test

Table 3. Comparison of demographics and operative parameters in patients receiving ETT vs. LMA

Variables	ETT		LMA		p value
	Median or Total (N)	IQR or Percentage (%)	Median or Total (N)	IQR or Percentage (%)	
Age	58.50	51.50 - 68.50	59.00	52.00 - 65.50	0.596[1]
Sex					
Female	10	55.6	16	53.3	0.881[2]
Male	8	44.4	14	46.7	
BMI	38.81	31.95 - 46.59	28.66	25.31 - 31.69	**< 0.001**[1]
Total Axial Stone Size Category (mm)					
8.0-12.0	8	44.4	10	33.3	0.553[2]
12.1-16.0	7	38.9	11	36.7	
16.1-20.0	3	16.7	9	30.0	
Stone Location					
Renal Pelvis	5	27.8	8	26.7	
Upper Pole	0	0	1	3.33	
Lower Pole	7	38.9	6	20.0	†
Proximal Ureter/UPJ	0	0	4	13.3	
Multiple locations	6	33.3	11	36.7	
Stone Density (HU)	888.5	681 - 1220	1296.5	1026 - 1455	**0.007**[1]
ASA Classification					
1	0	0	4	13.3	
2	2	11.1	15	50.0	†
3	15	83.3	10	33.3	
4	1	5.56	1	3.33	
Use of UAS					
Yes	17	94.4	28	93.3	†
No	1	5.56	2	6.67	
Lasing Mode					
Moses	7	38.9	17	56.7	0.233[2]
Standard	11	61.1	13	43.3	
Operative Time (minutes)	33.50	30.50 - 45.75	36.00	30.25 - 38.17	0.897[1]
Lasing Time (minutes)	13.22	9.69-25.38	16.88	11.32-24.04	0.711[1]
Total Number of Patients (N)	18		30		

[1]Two-tailed Mann Whitney U
[2]Chi-squared test
[†]Not enough samples in each group to accurately perform statistical test

Table 4. Multivariate Analysis Model of Lasing Inefficiency[1]

Variables	β coefficient	Standard error	p value
Anesthesia			
ETT	*Reference*		
LMA	6.186	2.712	**0.0276**
Axial Stone Size Category (mm)			
8.0-12.0	1.213	3.040	0.692
12.1-16.0	*Reference*		
16.1-20.0	-1.515	3.424	0.660
Number of Stones	-0.348	1.302	0.791
Sample Size	48		
R^2	0.12		

[1]Multivariate linear regression which includes method of anesthesia administration, axial stone size, and number of stones. BMI was not included in this analysis due to high collinearity with choice of airway securement by anesthesia.

A total of 48 patients were included in the study (Table 1). Median age was 59 years old (IQR 51.75 - 67.50) with 26 females and 22 males. 93.8% of the patients were Caucasian (N=45), 4.2% were African American (N=2), and 2.1% were Asian (N=1). 30 patients (62.5%) had an LMA in place during surgery while 18 (37.5%) had an ETT. In the univariate analysis (Table 2) comparing lasing inefficiency to multiple variables and study parameters, most variables were not statistically significant in affecting lasing inefficiency except method of securing patient airway by anesthesia (ETT vs. LMA). Patients who received an LMA had significantly higher lasing inefficiency (26.5%) compared to patients who received ETT (20.7%) ($p < 0.05$, One-tailed Mann Whitney U). Though BMI was not found to be significantly correlated with lasing inefficiency (Table 2), we noted that high patient BMI was significantly correlated with use of ETT over LMA as listed in Table 3 ($p < 0.001$, Two-tailed Mann Whitney U). We also noted that patients receiving an ETT had significantly lower stone density (HU) than those receiving an LMA as shown in Table 3 ($p < 0.01$, Two-tailed Mann Whitney U).

In the multivariate analysis (Table 4), LMA was also shown to have a statistically significant increase in lasing inefficiency compared to ETT. There was no increase in lasing inefficiency caused by increased stone burden. Since there was such a high degree of collinearity between BMI and use of ETT/LMA, BMI was not included in the multivariate analysis.

Discussion

The choice between patient airway securement with an ETT or LMA in urologic surgery has not been previously studied, and choice is dependent on various factors including hospital or physician preference, patient BMI, and aspiration risk. Some of the advantages to using an LMA include placement without use of muscle relaxants or direct laryngoscopy, lower anesthetic requirement, and higher overall tolerability compared to ETT.[5,6] However, due to supraglottic positioning, the LMA is unable to protect against risk of aspiration like an ETT, and without the use of continuous neuromuscular blocking agents, the anesthesiologist is unable to fully control the patient's respiratory mechanics. Additionally, the LMA is not the preferred primary airway device for patients with high BMI. In such patients, a higher positive airway pressure is required to adequately inflate the lungs which can lead to air leaks or risk of hypoventilation.[7] Thus, LMAs are typically reserved for shorter, less-invasive procedures in patients with low BMI and low risk of aspiration.

In certain urologic procedures such as transurethral resection of bladder tumor (TURBT), there are additional anesthetic considerations such as the requirement of the use of neuromuscular blocking agents to avoid activation of the obturator reflex during electrosurgical resection in lateral regions of the bladder.[8] Thus, in these cases an ETT would likely be used over an LMA. However, in most fURSL cases, an LMA can be used if there are no contraindications, though with the current lack of data it is difficult to determine which airway securement method is the most appropriate choice. Here, we aimed to quantitatively prove what had been perceived anecdotally – whether LMA or ETT anesthesia could prove to factor into the inefficiency of holmium laser operation – and therefore be added into consideration during lithotripsy procedures.

Overall, we noted a significant improvement in lasing inefficiency in patients who have an ETT compared to patients with an LMA (20.7% and 26.5%, respectively). This may be due to the potential decreased respiratory movement in patients with an ETT in place. However, no current research has investigated changes in patient respiratory movement between LMA or ETT (or with and without use of neuromuscular blocking agents). Also, as demonstrated by Table 3, there is a very significant correlation between high BMI and use of ETT over LMA, thus it is difficult to draw any conclusions on the effect of BMI on lasing inefficiency. This high correlation is likely due to concerns of airway securement in obese individuals.[9] Patients with high BMI are more likely to have comorbid metabolic conditions that may affect the choice of airway securement including restrictive pulmonary conditions due to excess body mass. These patients are also more likely to have comorbid diabetes which may lead to undetected gastroparesis and lead to retained stomach contents, further increasing aspiration risk.[5] Obesity is especially relevant in stone disease given increased risk of calcium oxalate and uric acid stones in obese individuals.[10]

One strength of this study was that fellowship-trained attending endourologists performed all the surgeries, reducing confounding from experience. Though, given our sample size, it is difficult to make definitive conclusions regarding lasing inefficiency given use of ETT or LMA without controlling for BMI, but the data does tend to support our hypothesis. Of the 48 patients in the study, 82.4% of patients with an ETT had a BMI ≥ 30.0, while 60.0% of patients with an LMA had a BMI < 30.0. An ideal future study would utilize a larger sample size with randomized assignment to ETT or LMA groups regardless of BMI. However, we also recognize that this may not be feasible due to the contraindications of LMA use in some populations. Besides the sample size, another major limitation of the study was the calculation of lasing inefficiency. Since the calculation of lasing pauses between firing has never been investigated in previous studies, validation of our calculation of lasing inefficiency is required with a larger and more diverse dataset. In one study by Wang et al. in 2021, evaluation of Moses laser lithotripsy efficiency primarily relied on overall operating time, number of times laser foot pedal was fired, laser working time in minutes, and laser pause time in minutes.[11] They then calculated a “stone fragmentation efficiency” defined as stone volume divided by laser working time, however, they did not use the duration between laser pauses to calculate their efficiency figure. Our approach adds more information to consider but requires further evaluation to hold true.

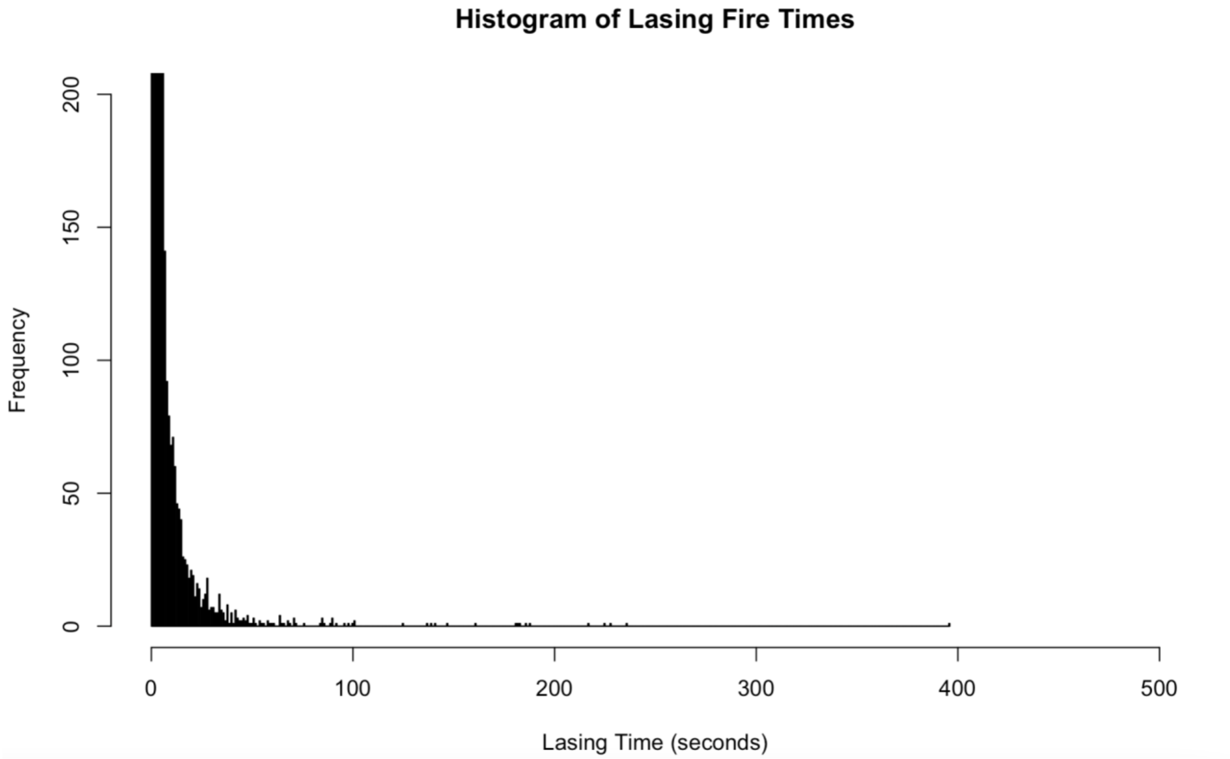
This data is thought provoking in that it applies a novel use of intraoperative data output with which to compare patient demographics and disease states. In the future, this type of algorithm can also be applied to other surgeries that utilize Holmium laser technology such as Holmium laser enucleation of the prostate (HoLEP). However, we must first expand the current dataset with more patients as more intraoperative data becomes available to better validate our calculations. We can also potentially apply machine learning techniques to analyze even larger data sets as more intraoperative laser logs are accumulated.

Conclusion

Our study demonstrates a novel analysis of previously unused intraoperative data output from Holmium P120H laser systems. Here, we utilized pause durations between laser activations to calculate a percentage inefficiency for each laser lithotripsy case and compared this to patient demographics, anesthesia airway securement, intraoperative parameters, and stone characteristics to determine significant factors that affect lasing efficiency. Our data supports the use of ETT over LMA to reduce lasing inefficiency when using Holmium lasers in fURSL. However, it remains one consideration among many when choosing between utilizing an LMA or ETT.

Appendices

Appendix 1.



This histogram consists of 5,293 data points representing elapsed time of individual laser firings across all 48 reviewed laser logs. The median for this data set is 3 seconds with an IQR of 1 - 5 seconds and range of 0 - 396 seconds. The y-axis was cut off at 200 to better show data points with lower frequency.

References

1. Dauw CA, Simeon L, Alruwaily AF, et al: Contemporary Practice Patterns of Flexible Ureteroscopy for Treating Renal Stones: Results of a Worldwide Survey. J. Endourol. 2015; **29**: 1221–1230.

2. Majdalany SE, Levin BA and Ghani KR: The Efficiency of Moses Technology Holmium Laser for Treating Renal Stones During Flexible Ureteroscopy: Relationship Between Stone Volume, Time, and Energy. J. Endourol. 2021; **35**: S14–S21.

3. Whitehurst L, Pietropaolo A, Geraghty R, et al: Factors affecting operative time during ureteroscopy and stone treatment and its effect on outcomes: retrospective results over 6.5 years. Ther. Adv. Urol. 2020; **12**: 1756287220934403.

4. Sonier M, Chu W, Lalani N, et al: Evaluation of kidney motion and target localization in abdominal SBRT patients. J. Appl. Clin. Med. Phys. 2016; **17**: 429–433.

5. Jannu A, Shekar A, Balakrishna R, et al: Advantages, Disadvantages, Indications, Contraindications and Surgical Technique of Laryngeal Airway Mask. Arch. Craniofacial Surg. 2017; **18**: 223–229.

6. Danks RR and Danks B: Laryngeal Mask Airway: Review of Indications and Use. J. Emerg. Nurs. 2004; **30**: 30–35.

7. Kim J-N, Lee J-Y, Shin K-J, et al: Haversian system of compact bone and comparison between endosteal and periosteal sides using three-dimensional reconstruction in rat. Anat. Cell Biol. 2015; **48**: 258–261.

8. Panagoda PI, Vasdev N and Gowrie-Mohan S: Avoiding the Obturator Jerk during TURBT. Curr. Urol. 2018; **12**: 1–5.

9. Mason-Nguyen JA and Rodriguez RE: Laryngeal Mask Airway Use in Morbidly Obese Patients Undergoing General Anesthesia. AANA J. 2017; **85**: 130–135.

10. Poore W, Boyd CJ, Singh NP, et al: Obesity and Its Impact on Kidney Stone Formation. Rev. Urol. 2020; **22**: 17–23.

11. Wang M, Shao Q, Zhu X, et al: Efficiency and Clinical Outcomes of Moses Technology with Flexible Ureteroscopic Laser Lithotripsy for Treatment of Renal Calculus. Urol. Int. 2021; **105**: 587–593.