Original Article

Evaluation of pulse modulation settings for optimal pop-dusting efficiency using the Quanta Litho 150 laser: An *in vitro* study

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Abstract

Purpose: The novel Quanta Litho 150 W (Samarate, Italy) was recently introduced and incorporates new pulsed modulation settings. We sought to analyze ablation rate and efficiency in short pulse (SP), virtual basket (VB), and vapor tunnel (VT) pulsed modulations, in an *in vitro* pop-dusting simulation across different settings at a fixed power of 30 Watts (W) and fixed periods of time.

Materials and Methods: Seven millimeter BegoStone phantoms were subjected to lithotripsy in a simulated calyx using Holmium: yttrium:aluminum garnet Quanta System 150 W. 30 W was applied at different settings across three pulse modulation modes: SP, VB, and VT. Ablation rate and efficiency were and compared between the three groups.

Results: Maximum ablation efficiency for the VB and VT groups was achieved at VB 2J x 15 Hz and VT at 2.5 J x 12 Hz. Ablation efficiency decreased with higher Joules. VB at 1.5 J x 20 Hz and SP at 2.5 J x 12 Hz were the only settings to obtain 85% ablation at 5 min.

Conclusions: *In vitro* laser lithotripsy using a BegoStone phantom, VB at 2J x15 Hz and VT at 2.5 J x 12 Hz were the most efficient setting for pop-dusting with the Quanta Litho 150. The highest efficiency (mg/min) was achieved with VB at 2 J x 15 Hz and VT at 2.5 J x 12 Hz at 1:15 min.

Keywords: Calyx, lithotripsy, pop-dusting, short pulse, virtual basket, virtual tunnel

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INTRODUCTION

Holmium: Yttrium:aluminum garnet (Ho:YAG) is the gold standard laser for renal stone treatment and is widely used in endourological procedures.[1-4] Ho:YAG is a 2.1 μm wavelength pulsed laser that is highly absorbed in water and produces ablation mechanism by photothermal effect.[5] The amount of energy delivered in lithotripsy depends on the pulsed energy (PE) and frequency Total power (W) = Pulse energy (Joules) × Frequency (Hz). "Pop-dusting" is a technique that uses high frequencies and low PE to break stones into fine particulate. This combines an initial dusting modality and a subsequent noncontact dusting modality, which reduces the necessity for stone retrieval through endoscopic basket extraction.[6] Pop-dusting modalities

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have shown satisfactory stone-clearing results in adult and pediatric population.[7-9]

Significant advancement and modification of laser technology has yielded newer lasers with diverse features. The novel Quanta Litho 150 W (Samarate, Italy) was recently introduced which has the capacity to emit high power (up to 150 W), with combination of increased frequency (up to 100 Hz), high pulse energy (up to 5 J), and high versatility in pulse width adjustment allowing for individualized stone treatment depending on the stone location and characteristics.[10,11] virtual basket (VB) and vapor tunnel (VT) settings are recent technologies developed by Quanta System (Samarate, Italy) generating longer bubbles leading to increased ablation rate with reduced retropulsion.[11] VB uses a double pulse energy modulation, producing a vapor bubble with the first pulse. A second pulse is then transmitted through the bubble, facilitating bubble propagation to increase the effective distance. VT produces a single long pulse designed to minimize peak power. This single long pulse creates a long bubble that connects the fiber with the stone.[12] These new pulse modulation techniques are supposed to improve the ablation efficiency by reducing stone movement. Currently, there is lack of data providing evidence of this hypothesis.

The utilization of 30 W and 100 W holmium laser has been proven to be safe and effective with high success rate, low complication rates and reduced operative time.[13-15] We sought to analyze the ablation rates and ablation efficiency of Ho:YAG Quanta Litho 150 W (Samarate, Italy) in an *in vitro* pop-dusting simulation across different settings at a fixed power of 30 W, using VB, VT, and short pulse (SP). This study will help us in findings the ideal settings for pop dusting of stones using Ho:YAG Quanta Litho 150 W.

MATERIALS AND METHODS

Stone phantom

Stone phantoms were created to simulate pelvicalyceal kidney stones using a 2:1 mixture of BegoStone Plus to water and set in 7 mm diameter spherical silicone molds, creating a density of 1.30 g/cm³, mean weight 0.239 ± 0.013 g. We used a Precision Laboratory Analytical Balance Lab Scale 500 g × 0.001 g accuracy to weigh the phantoms. The stones were left to dry at room temperature at least 24 h before performing each experiment.

Experimental setup

An *in vitro* experimental study was conducted simulating a renal calyx [Figure 1]. We used a 5 mL syringe, with an internal diameter of 13 mm to simulate the lumen of the calyx. The piston of the syringe was fixed at 4 mL to better replicate the calyx and to prevent excessive movement from irrigation or laser-emitted energy. A 10/12 Fr dual lumen ureteral access catheter (Cook, Bloomington, IN, USA) was inserted through a small hole in the piston, with the tip of the catheter protruding 6 mm from the end of the piston such that both working channels were available for use. A 272 μm Optical Reusable Fiber (Quanta System, Samarate, Italy) was positioned in the central working channel and the lateral channel was used as inflow irrigation. The laser fiber was fixed at the 2 mL mark in the 5 mL syringe.

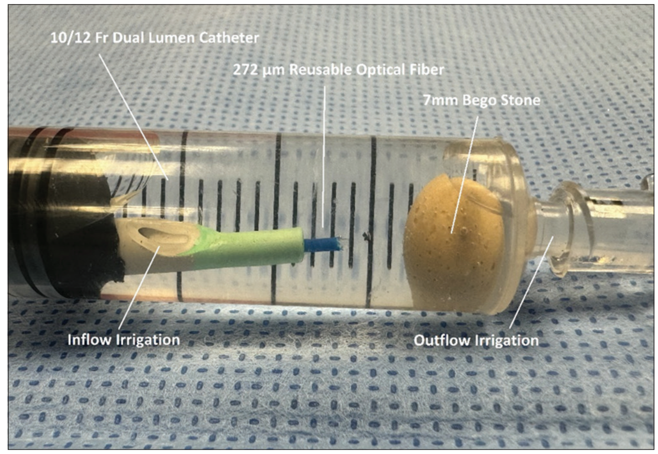

Figure 1: Simulated 13 mm lumen Calyx with a 7 mm stone, 10/12 Fr dual lumen catheter used for water inflow and fiber placement

For irrigation, we used a 3-L bag of 0.9% saline at room temperature, positioned one meter above the working table. We used the Luer lock portion of the syringe as the outflow of the irrigation by adding an extension catheter, positioned at the same level as of the experimental table.

The high-power Ho:YAG Quanta Litho 150 W laser (Samarate, Italy) was used with a 272 μm Optical Reusable Fiber for the experiment. BegoStone phantoms measuring 7 mm were subjected to lithotripsy across a range of settings with fixed power of 30 W: (0.4 J × 80 Hz), (1 J × 30 Hz), (1.5 J × 20 Hz), (2 J × 15 Hz), and (2.5 J × 12 Hz) across the three pulse modulation modes VB, VT, and SP. All trials were performed with a continuous gravity outflow rate. Each trial began with a new phantom and was run continuously at a given mode and power for 4 fixed time intervals T1 (1:15), T2 (2:30), T3 (5:00), or T4 (7:30) minutes. Trials were performed in triplicate across each duration and mean of the values was taken. Before each trial, the laser fiber was conditioned (stripped and cut) following the manufacturers recommendation using the fiber striper (Quanta System, Samarate, Italy). Residual stone dust was collected utilizing Fisherbrand™

Quantitative Grade Filter Paper with particle retention 1–5 μm. The residual phantom at the end of each designated time interval was removed from the cylinder; both were dried at room temperature for at least 24 h. Ablated stone mass loss (mg) and percentage of ablation were calculated from the weight difference before and after lithotripsy.

Ablation efficiency was calculated as the mean milligram loss per minute (mg/min), from the different number of tests at different periods of time.

Ablation efficiency = Mean milligram loss/time interval (T1, T2, T3, or T4)

Complete ablation was defined as >85% mass reduction, as this would make the stone to measure <1 mm.

Once we had performed all of the trials, we compared the efficiency and performance of the 3 best settings with the pulsed modulation modes at 1:15 min and 7:30 min [Figure 2].

Statistical analysis

Analysis comparing the different laser settings for each pulse module was performed using one-way analysis of variance with Tukey *post hoc* comparisons. *T*-test analysis was performed to evaluate the difference between the groups in continuous variables. $P < 0.05$ was considered to be statistically significant. Descriptive and statistical analyses were performed using IBM SPSS Statistics version 27, Armonk , New York.

RESULTS

Laser device and settings

Five frequency/joule combinations were assessed with each of the three pulse modulation modes over the four time periods. Each test was repeated three times, yielding 180 total trials.

Percentage of ablated mass (ablation performance)

The ablation rates were calculated for all 180 lithotripsy trials [Table 1 and Figure 3]. All trials were able to reach duration up to 7:30.

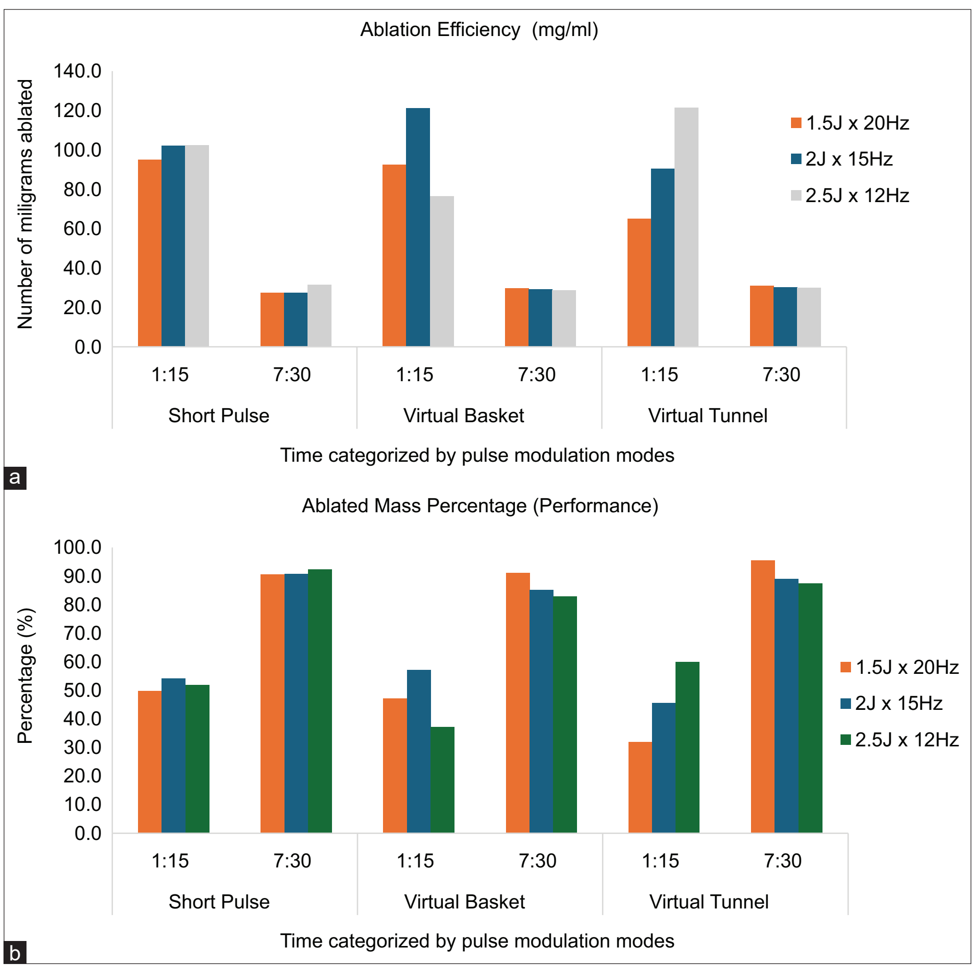

Figure 2: Ablation efficiency (mg/ml) with trendlines for 2 J × 15 Hz and 2.5 J × 12 Hz (a) and ablated mass percentage (b) categorized by best observed settings. Hz: Hertz

The longer the time of ablation, higher the ablation mass percentage (ablation performance) across all trial variations.

With SP complete ablation was achieved at 5 min with 2.5 J × 12 Hz settings. With VB complete ablation was achieved at 5 min with 1.5 × 20 and 2.5 × 12. With VT complete ablation was achieved at only 7.5 min with all 4 settings except 1 J × 30 Hz.

With SP highest performance (ablation mass) was reached irrespective of energy settings, whereas with VB and VT highest performance was seen with low energy and higher frequency and gradual declined with increase in energy and reduction in frequency.

SP ablation peaked at >90% of ablated mass at 7:30 min in 1.5 J, 2 J, and 2.5 J [Figure 3a]. For VB and VT, mean ablation percentage peaked at 1.5 J × 20 Hz ($P = 0.001$), and then decreased as Joules increased and Hz reduced [Figure 3b and c].

Ablation efficiency

Mean ablation efficiency was measured in mg/min and is listed in Table 2 and Figures 2, 4. Overall, the longer

Table 1: Mean ablation percentage of short pulse, virtual basket, and vapor tunnel at fixed periods of time at fixed power of 30W

Settings			Pulsed modulation mode			*P*
Joules	Hertz	Time	SP ablation (%)	VB ablation (%)	VT ablation (%)	
0.4	80	7:30	84.35 (71.6–96.4)	75.30 (66.1–85.4)	88.50 (94.6–78.2)	0.001
0.4	80	5:00	67.36 (64.1–74.2)	70.89 (50.6–92.9)	54.15 (45.2–60.8)	0.36
0.4	80	2:30	57.40 (50.2–63.4)	33.84 (28.4–40.6)	40.90 (50.4–35.2)	0.02
0.4	80	1:15	40.59 (27.5–54.4)	35.08 (17.4–50.9)	18.95 (23.0–12.9)	0.001
1	30	7:30	77.76 (64.3–87.3)	80.97 (65.8–92.5)	69.80 (63.5–80.8)	0.001
1	30	5:00	67.94 (51.9–84.7)	78.50 (67.4–86.0)	67.77 (61.0–76.8)	0.03
1	30	2:30	40.95 (17.3–55.6)	64.82 (55.7–72.7)	47.48 (43.8–54.2)	0.02
1	30	1:15	40.38 (32.4–54.4)	46.74 (46.0–48.5)	23.24 (10.5–41.3)	0.001
1.5	20	7:30	90.60 (82.3–96.3)	91.14 (89.2–93.0)	95.49 (91.5–99.6)	0.001
1.5	20	5:00	59.11 (50.9–63.6)	86.51 (78.3–92.4)	80.60 (56.4–96.4)	0.003
1.5	20	2:30	53.20 (50.0–59.0)	47.27 (35.7–63.9)	53.20 (48.3–59.0)	0.236
1.5	20	1:15	49.74 (46.3–55.3)	47.18 (41.1–54.4)	31.80 (18.7–42.3)	0.001
2	15	7:30	90.79 (79.1–97.8)	85.05 (76.8–89.7)	89.05 (71.1–99.2)	0.001
2	15	5:00	74.09 (67.2–83.9)	72.74 (60.0–80.3)	70.99 (59.9–83.4)	0.364
2	15	2:30	80.23 (68.8–86.2)	67.24 (62.6–70.1)	67.22 (56.0–74.8)	0.236
2	15	1:15	54.10 (43.2–74.1)	57.18 (50.4–63.5)	45.61 (42.6–55.5)	0.001
2.5	12	7:30	92.34 (87.2–97.0)	82.84 (75.0–92.8)	87.41 (70.3–99.6)	0.001
2.5	12	5:00	85.17 (77.3–92.3)	83.50 (60.4–93.7)	71.43 (62.4–81.5)	0.003
2.5	12	2:30	74.78 (69.4–81.4)	62.46 (53.1–69.9)	62.65 (60.1–64.4)	0.236
2.5	12	1:15	51.98 (30.8–79.0)	37.16 (27.0–46.2)	59.84 (42.6–76.3)	0.001

SP: Short pulse, VB: Virtual basket, VT: Vapor tunnel

Table 2: Mean efficiency of short pulse, virtual basket, and vapor tunnel at fixed periods of time at fixed power of 30W

Settings			Pulse modulation mode			*P* (α 0.05)
Joules	Hertz	Time	SP efficiency (mg/min)	VB efficiency (mg/min)	VT efficiency overall (mg/min)	
0.4	80	7:30	28.67 (27.9–32.5)	25.60 (20.0–32.2)	30.27 (26.9–32.9)	0.001
0.4	80	5:00	34.27 (29.2–38.6)	37.00 (25.6–49.4)	28.33 (24.8–31.0)	0.69
0.4	80	2:30	57.73 (46.4–65.2)	33.73 (25.2–41.2)	42.67 (39.2–48.8)	0.32
0.4	80	1:15	84.80 (55.2–117.6)	72.53 (73.6–112)	37.87 (26.4–44.8)	0.001
1	30	7:30	25.73 (20.9–30.1)	26.62 (20.5–33.1)	23.82 (19.3–29.8)	0.35
1	30	5:00	35.07 (27.0–42.2)	41.93 (37.2–46.8)	33.47 (28.2–38.6)	0.35
1	30	2:30	44.27 (19.2–59.2)	67.33 (56.4–75.6)	46.93 (39.6–58.8)	0.78
1	30	1:15	83.20 (70.4–108.8)	96.27 (85.6–101.6)	46.13 (20.0–84.0)	0.001
1.5	20	7:30	27.42 (24.7–31.6)	29.78 (26.5–32.0)	31.07 (28.8–34.5)	0.001
1.5	20	5:00	27.07 (22.8–30.4)	42.67 (41.2–46.4)	42.00 (27.2–49.6)	0.003
1.5	20	2:30	51.07 (46.8–53.6)	46.27 (38.0–58.8)	53.07 (46.8–60.0)	0.321
1.5	20	1:15	94.93 (90.4–108)	92.53 (73.6–119.2)	65.07 (36.8–88.8)	0.001
2	15	7:30	27.33 (24.3–29.9)	29.16 (23.9–32.1)	30.27 (22.0–37.0)	0.001
2	15	5:00	34.20 (28.4–40.6)	37.47 (24.0–45.2)	37.33 (29.6–44.0)	0.03
2	15	2:30	75.07 (68.8–81.6)	66.40 (63.2–70.4)	70.13 (57.2–79.6)	0.78
2	15	1:15	102.13 (73.6–141.6)	121.07 (97.6–135)	90.40 (79.2–104.0)	0.001
2.5	12	7:30	31.56 (27.3–34.6)	28.67 (23.6–34.5)	30.00 (21.8–34.9)	0.01
2.5	12	5:00	44.20 (39.4–50.4)	42.00 (27.4–53.8)	36.93 (32.2–40.6)	0.25
2.5	12	2:30	78.27 (67.2–88.0)	64.67 (48.4–76.0)	64.53 (59.2–67.6)	0.5
2.5	12	1:15	102.40 (95.2–144.8)	76.53 (59.2–92.0)	121.33 (81.6–155.2)	0.001

SP: Short pulse, VB: Virtual basket, VT: Vapor tunnel

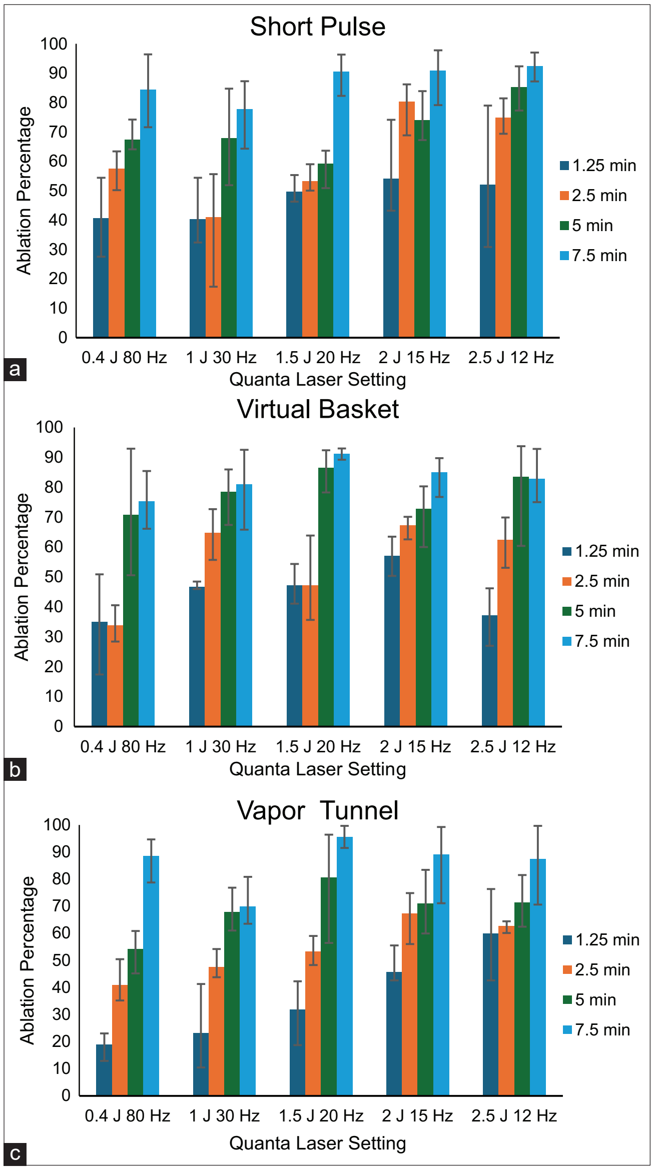

Figure 3: Ablation percentage (performance) graphs comparing settings for individual laser modalities. Hz: Hertz

the time, the less the ablation efficiency. Mean ablation efficiency was highest in the initial time period of (1:15 min) which was true across all settings. Efficiency continued to decline as the time increased, with 7:30 min being the least efficient. Ablation efficiency was highest with VB 2 J × 15 Hz and VT 2.5 J × 12 Hz at 1:15 min [Table 2 and Figures 4b, 4c]. Ablation efficiency was good with SP but was uniform at approximately 90–100 mg/mL irrespective of energy settings.

The greatest efficiency was seen for two settings, both at 1:15 min: VB at 2 J × 15 Hz (P = 0.001), and VT at 2.5 J × 12 Hz (P = 0.001) [Figures 2a, b and 4b, c]. In general, there is more efficiency with higher power and lower frequency.

DISCUSSION

We performed a total of 180 trials for pulsed modules: SP, VB, and VT at 4 different fixed times. To the best of our knowledge, this is the first study aiming to quantify ablation and determine the most efficient settings for VB, SP, and VT at 30W in the Quanta Litho 150 W (Quanta System, Samarate, Italy) by evaluating ablation percent and efficiency in a simulated renal calyx.

In our *in vitro* experiment, most efficient ablation was achieved with VB at 2 J × 15 Hz and VT at 2.5 J × 12 Hz. At 1:15 min, VB at 2 J × 15 Hz, and VT at 2.5 J × 12 Hz achieved the highest efficiency (mg/mL) and highest percentage of ablated mass [Figure 2a and 2b].

Complete ablation (defined as >85% of ablated mass), was reached with VB using settings of 1.5 J × 20 Hz and SP with 2.5 J × 12 Hz at 5:00 min of continuous lithotripsy on the 7 mm BegoStone simulating a kidney stone in the calyx [Table 1 and Figure 3a and b]. Higher ablation rate with VB compared to other pulsed modulation techniques has been reported in the literature. Ballesta *et al*.,[12] ablated hard and soft phantom BegoStones using the Quanta Cyber Ho 150 with different combinations of power, energy, and frequency (10 W = 0.5 J × 20 Hz, 10 W = 0.5 J × 20 Hz, 60 W = 1 J × 60 Hz, and 60 W = 2 J × 30 Hz). VB technology was related to the highest ablation rates for hard and soft stones, compared to VT. Ballesta Martinez *et al*.,[5] looking to analyze the BegoStone ablation rates of Ho:YAG at different settings around 12 W concluded that the highest ablation rate was obtained with 40 Hz/0.3 J with VB. Şirin *et al*.[16] examined the effects of VB on kidney tissues. Using high-power output (40, 60, and 80 W), VB allowed for controlled dissection of the kidney tissues with a lack of large vaporization area during surgical procedures, suggesting that VB is safe and useful for tissue surgery. Yamashita *et al*.[17] evaluated the retropulsion rate for VB, SP and long pulse modes using the Moses Mode (MM). He concluded that retropulsion in millimeters was shorter with VB compared to MM. We also hypothesize that one of the main reasons that VB reached complete ablation under 5:00 min in our study is because VB produces less retropulsion due to its double bubble effect, permitting more consistent laser-stone energy transfer.[4]

We calculated the ablation efficiency in mg/min using a fixed power of 30 W and fixed intervals of time at 1:15, 2:30, 5:00, and 7:30 min. In all pulse modules (VB, SP, and VT), the mean ablation efficiency increases with settings of higher energy (joules) and lower frequencies (Hz), consistent with previous studies.[3] The greatest

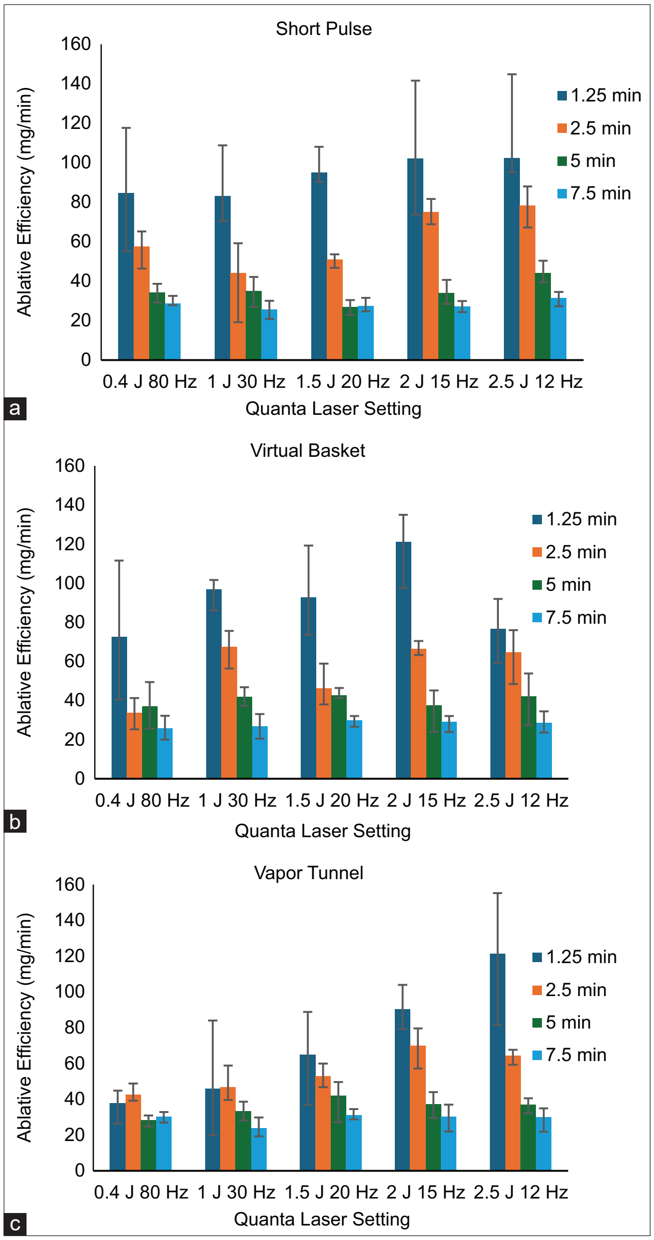

Figure 4: Ablation efficiency graphs comparing settings for individual laser modalities. Hz: Hertz

efficiency (mg/ml) settings were VB at 2 J × 15 Hz and VT 2.5 J × 12 Hz at 1:15 min [Figure 4b and c]. It a was noted that efficiency decreased as time length increased, despite ablation percentage increasing over additional time. This is somewhat expected and on-target lasing decreases as the target becomes smaller from previous successful hits, especially in a model with a fixed laser fiber. Initial efficiency (i.e., at the shorter time frames) is likely the more relevant statistic in this model, speaking to the ability to quickly reduce a fresh stone.

From our experiments, SP efficiency was relatively consistent across different settings within a given block of time, and VB was similar to these as well, aside from the maximum efficiency setting at the previously mentioned 2J ×15 Hz for 1:15 min. VT technology is the result of the pulse modulation that consists of a single specific long pulse, using the minimum peak power in accordance with selected output settings, designed to reduce retropulsion and to lower dusting times.[18] Efficiency is of unclear significance.

This study has limitations which impact clinical applicability. The experimental setup implemented a fixed power level of 30W, aimed to replicate a stone in an end calyx using off-the-shelf parts, and had fixed fiber positioning, all of which differ from real-world lithotripsy scenarios. In addition, all trials used the Optical Reusable Fiber (Quanta System, Samarate, Italy) which could introduce variation compared to opening a fresh fiber for every trial. Attempts were made to limit this by refreshing the fiber according to manufacturer recommendations and many studies have shown that reusable fibers do not affect the ablation rate.[8,9] This study did not measure retropulsion, but retropulsion can be indirectly inferred from efficiency, where increased efficiency may be related, at least in part, to reduced retropulsion.

Our results can be a hypothesis generator that can be used for clinical practice or further similar *in vitro* studies. Our main objective was to look for the best setting, looking to reach a time point for complete ablation and looking at ablation efficiency under fixed points in time.

Further avenues of research include assessing this laser system (and others) at various power levels using the systems available pulse modulation paradigms in either a less controlled *in vitro* experiment simulating the renal calyx or in clinical studies. Efficiency likely varies based on stone composition and resulting hardness, which should be explored.

CONCLUSIONS

In this *in vitro* phantom stone ablation experiment with the novel Quanta System Litho 150 W, Virtual Basket™ and Vapor Tunnel™ pulse modulation maximum ablation efficiency in mg/ml and ablated mass percentage was achieved with Virtual Basket™ at 2 J × 15 Hz and Virtual Tunnel™ at 2.5 J × 12 Hz at 1:15 min.

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Conflicts of interest

SQ: Advisor, Coloplast Corp.(Minneapolis, MN); HoLEP preceptor, Cook Medical (Bloomington, IN); HoLEP preceptor, Richard Wolf Medical Instruments Corp. (Vernon Hills, IL). The other named authors have no other conflicts of interest, financial or otherwise, to declare.

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