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A review of the Moses effect and its applications in endourology

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Abstract

The holmium:yttrium aluminum garnet laser, the gold standard for lithotripsy, is widely used in various endourological fields. Their physical characteristics contribute to the Moses effect. This narrative review aimed to analyze the current knowledge of the Moses effect and its applications in endourology. The Moses effect involves the rapid formation of a vapor bubble that allows the remaining energy to reach the target with less attenuation. Lumenis® developed pulse modulation technology, the MOSES™ technology, that harnesses the Moses effect to optimize holmium energy. Preclinical studies concluded that the new technology improves stone retropulsion, allowing for reduced lithotripsy duration. However, the heterogeneity of clinical studies and the lack of randomized controlled trials do not allow definitive conclusions. The MOSES™ technology has also been applied in holmium laser enucleation of the prostate, reducing enucleation and hemostasis times, leading to improved enucleation efficiency. However, minimal changes occurred in hemoglobin or hematocrit levels and no significant differences were noted in complications or functional outcomes. Further research is needed to fully evaluate the benefits and limitations of MOSES™ technology in clinical practice.

Keywords: Moses effect; Holmium:yttrium aluminum garnet; Lithotripsy; Benign prostatic hyperplasia; Holmium laser enucleation of the prostate

1. Introduction

In recent decades, the development of new technologies such as lasers in the surgical treatment of benign prostatic hyperplasia has allowed the evolution of minimally invasive techniques that offer results comparable to those of transurethral resection of the prostate with a lower complication rate.[1] Laser is the most commonly used energy source in endoscopic lithotripsy to the detriment of other lithotripters, and it is being increasingly used in upper tract urothelial carcinoma and en bloc resection of bladder tumors.[2]

The holmium:yttrium aluminum garnet (Ho:YAG) laser is the current gold standard in lithotripsy.[3] Holmium laser enucleation of the prostate (HoLEP) is more effective than transurethral resection of the prostate and comparable to open prostatectomy but with fewer complications.[4] The holmium:yttrium aluminum garnet (Ho:YAG) is a solid-state pulsed laser with an infrared wavelength of 2120 nm that is strongly absorbed by water, leading to the rapid formation of vapor bubbles with each laser pulse. After bubbling, the remaining energy reaches the target with less attenuation.[5] This phenomenon was first described in 1986 in an endovascular application and was named the "Moses effect," referring to the leader of the people of Israel who crossed through the Red Sea during their exodus from Egypt.[6]

This narrative review aimed to describe the Moses effect and its application in stone and benign prostatic hyperplasia laser treatment.

2. Moses effect: Definition and applications

Although the first laser was developed 60 years ago, the basis of laser technology was described at the beginning of the 20th century. Most early lasers emitted continuous energy; however, they were not as effective as lithotripters in addition to producing heat that could harm the urinary tract. In contrast, pulsed lasers such as the Ho:YAG act as percussion drill machines; they are faster, are more efficient, and emit less heat. Furthermore, pulsed lasers are preferred over continuous wave lasers for soft tissue applications because of their precise control over the ablation process.[7] These properties make Ho:YAG lasers the gold standard for laser lithotripsy.[3]

The wavelength of the holmium laser was 2120 nm, close to that of the infrared water absorption peaks (1910 nm). Consequently, the Ho:YAG laser was highly absorbed by water, leading to the rapid formation of vapor bubbles, and the amount of energy delivered to the target decreased. This gives the Ho:YAG laser a higher safety profile because the theoretical optical penetration depth is limited to 400 μm and tissue coagulation beyond this distance requires a higher pulse energy range.[8]

Vapor bubble formation was first described by Isner et al.[9] in 1986 at the 59th Annual Scientific Session of the American Heart Association. Two years later, they published the results of their in vitro experiment in which the myocardium was ablated using two different pulsed lasers (CO_2 and XeF excimer) through blood and water. Using high-speed photography, the researchers recorded the formation of "dynamic optical cavities," which they inferred consisted of vapors and that this steam tunnel serves as a pathway that allows the transmission of radiation to submerged tissue.[10] They termed this phenomenon the "Moses effect".[6]

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Royston et al.[11] quantified the Moses effect for the first time and observed an unexpected increase in the transmission (up to 10%) of neodymium:yttrium aluminum garnet laser radiation in a 50/50 blood-saline solution. Later, van Leeuwen et al.[5] determined that the penetration depth of holmium: yttrium-scandian-gallium-garnet (Ho:YSGG) laser pulses in saline or blood was 3.6 times greater than the expected depth predicted by the water absorption coefficient. These findings were also observed in urine using Ho:YAG lasers.[12] Therefore, for the Moses effect to occur, the laser energy must be absorbed by water. The laser wavelength is the deciding factor. For example, a frequency-doubled double-pulse neodymium:yttrium aluminum garnet laser, whose wavelengths are 532 and 1064 nm, is primarily absorbed by stones instead of water. Consequently, cavitation bubbles are generated as a result of the initial vaporization of the stone surface, and the larger the laser fiber-stone distance, the shorter the bubble lifetime. In contrast, because of the Moses effect, the bubble size and lifetime increase with increasing fiber-stone distance using a holmium laser.[13]

The holmium:yttrium aluminum garnet laser has a high peak power. It means that a high proportion of energy is delivered at the beginning of its pulse, which is mostly absorbed by water. Thus, a significant proportion of the energy is wasted in creating the bubble, and the direct transmission of laser light is not possible at distances greater than 4 mm because of the complete absorption of pulse energy by water. Although this gives a Ho:YAG laser a good safety profile, the energy received by the target is significantly less than the energy emitted.[14] The high peak power and rapid expansion and collapse of the bubbles provide a mechanical contribution to laser ablation and could aid in better dissection during laser enucleation of the prostate. However, it generates a transient pressure that causes undesired retropulsion.

Several studies have reported various approaches to modulating the Moses effect, which have paved the way for clinical applications aimed at mitigating Ho:YAG retropulsion. A significant correlation between laser fiber diameter and maximal cavitation bubble size was demonstrated, and larger bubbles were noted when more energy per pulse was employed.[15] Furthermore, the peak power decreases with a longer pulse duration, and the vapor bubble dynamics change to an elongated pear shape with reduced shock wave pressure compared with spherical bubbles in short pulses.[7,16] This could lead to less stone retropulsion and reduced collateral mechanical tissue damage such as tissue fissures caused by short pulses and high-energy holmium lasers as reported by van Leeuwen.[5,7] Other methods have also been described, such as the use of lower pulse energies or smaller fibers. However, these solutions appear to reduce ablation efficiency.[3,7] To optimize the energy supply while reducing adverse effects, Lumenis® developed a pulse modulation system, called MOSES™ technology, that modifies the vapor bubble channel.[17]

3. Moses™ Technology

One of the earliest reports on the Moses effect associated with a holmium laser indicated that the vaporization fluid can absorb at least 50% of the emitted energy before the vapor bubble reaches the target. This report also stated that vapor bubble formation begins within the first 50 microseconds of the laser pulse and grows up to 1 mm long in the first 100 microseconds and up to 2 mm long within 200 microseconds.[5] Subsequent research by the same team revealed that a vapor bubble can be initiated with a small amount of laser energy and that the speed of bubble formation is relatively independent of the pulse duration or energy.[18] To enhance the efficiency of Ho:YAG, Trost[19] devised and patented a new pulse format consisting of a first pulse with an ideal energy level to initiate vapor bubble formation, followed by a second pulse that maximizes energy delivery. Trost[19] proposed a formula that estimates that a vapor bubble can be created using only 1%–2% of the laser's emitted energy.

Building on this, Lumenis® created MOSES™ technology for the MOSES™ Pulse 120H laser system, which divides the holmium laser pulse into two adjacent peaks. The first pulse is short and has low energy (approximately 20% of the total energy) that separates the water, while the second pulse delivers the remaining 80% of the energy toward the target pulse with less energy dissipation.[20] As Ventimiglia et al.[21] demonstrated, MOSES™ technology confers lower peak power and a longer pulse to Ho:YAG compared with standard mode short pulse (SP) but similar to long pulse (LP).

According to the manufacturers, these features have several clinical applications. On the one hand, the smaller the lower retropulsion and the faster fragmentation of the stones reduces procedure time in stone surgery. In contrast, faster enucleation and hemostasis reduce surgical time and improve vision because better hemostasis offers a faster learning curve in HoLEP.[17] Moreover, to accommodate different clinical scenarios in stone endoscopic procedures, there are two different MOSES™ technology settings depending on the fiber-target distances: Moses Contact (MC) is optimized for short-distance lithotripsy (approximately 1 mm), while Moses Distance (MD) is optimized for use at a distance (approximately 2 mm) that could be effective for stones that are difficult to access due to the calyx anatomy or for the popcorn technique.[22,23]

Aldoukhi et al.[24] demonstrated the differences in the shapes of vapor bubbles among SP, LP, MC, and MD. Short pulse generates an asymmetrically round bubble, whereas LP produces an asymmetrically pear-shaped bubble. The MC and MD modes of the first bubble were similar to but smaller than those of the SP bubble, and the second bubble extended from the tip of the initial bubble when it reached its maximum expansion. The initial MC bubble is smaller than the initial MD bubble, whereas the second MD bubble seems to reach a greater distance.[24] For the SP and LP modes, all of the energy is delivered in one or two pulses; therefore, most of the energy is lost, forming a vapor bubble.[25] Other companies have developed similar pulse modulation systems, such as Virtual Basket™ from Quanta System® and Stabilization mode™ from Olympus®.[20,26,27]

Another laser technology is emerging and could compete against Ho:YAG with or without MOSES™ technology: the thulium fiber laser (TFL). A TFL is a diode laser that emits light through a fiber doped with thulium ions. Its 1940-nm wavelength, which is much closer to the water absorption peak than that of the Ho:YAG, results in an optical penetration length 4 times shorter than that of the Ho:YAG laser, improving tissue ablation safety. The Moses effect also occurs in TFL, producing multiple bubbles in a single laser pulse that grow and collapse without interference.[8,26–28] In addition, an analysis of the bubble dynamics demonstrated that the TFL bubble dimensions were 4 times smaller than those of Ho:YAG laser because of the lower peak power. Consequently, pressure transients measured 0.6 and 7.5 bars, respectively, confirming that TFL produces less stone retropulsion.[29]

4. Moses™ technology in lithotripsy

Laser lithotripsy occurs mainly through a photothermal ablation mechanism: the direct absorption of infrared radiation by the stone increases the temperature, which chemically degrades it. This phenomenon was evident in a morpho-constitutional analysis of the disintegration products of holmium lithotripsy, which revealed the conversion of calcium oxalate dihydrate to calcium oxalate monohydrate, changes to an amorphous carbapatite phase and the appearance of hydroxyapatite hexagons in the brushite fragments. At equivalent pulse energy, MOSES™ technology showed marked differences due to the higher laser beam delivery. In addition to the photothermal effect, mechanical ablation occurs because of the collapse of vapor bubbles on the surface of the stone. Nevertheless, the energy produced during this shock wave plays a limited role in stone fragmentation, so it is more important that the maximum laser energy reaches the target as provided by MOSES™ technology. In addition, the pressure waves generated by the collapse of vapor bubbles at the tip of the fiber and on the surface of the stone moved the stone, inducing retropulsion.[30–33] Retropulsion forces the urologist to move the ureteroscope and fiber to the new stone position, which can increase operative time and difficulty. The use of longer pulse durations, lower pulse energies, and smaller fibers results in the desired reduced stone retropulsion.[30,34]

Several studies have evaluated the effects of MOSES™ technology on stone retropulsion and stone ablation. Elhilali et al.[22] conducted the first preclinical study to evaluate lithotripsy with MOSES™ technology using different settings and fiber sizes. The MC and MD modes produced less retropulsion than the regular mode ($p < 0.05$). They also found a significantly higher flexibility of the 200-μm Moses fiber versus the conventional 200-μm fiber.[22] Another in vitro experiment showed a significant reduction in subjective assessment of stone retropulsion in MOSES™ versus regular mode. This became clear when the number of times the Ho:YAG laser pedal was pressed 86 versus 43 times ($p < 0.01$) during fragmentation and 50 versus 26 times ($p < 0.01$) during pulverization. This means that there is less time to stop and relocate the endoscope to continue lithotripsy. This led to a significant reduction in the overall procedure time for both fragmentation (35%) and dusting (23%).[35] Ventimiglia et al.[21] tested stone displacement by comparing SP, LP, and MOSES pulses (MPs). After a 1-second laser and the use of equivalent settings, the retropulsion for LP and MP was similar (10 ± 6 vs. 8.6 ± 6.1 mm; $p = 0.69$) but lower than that for SP (21 ± 12 mm; $p < 0.01$). In addition, LP and MP demonstrated similar stone ablation volumes (0.16 ± 0.08 and 0.19 ± 0.09, respectively; $p = 0.29$).[21]

Stone ablation was significantly superior when Moses modes were used, becoming more than twice as high in dusting setting with 365-μm fibers.[22] Because of the dynamics of the vapor bubble and the already exposed laser beam, the volume of the stone crater was significantly dependent on the distance between the fiber and the stone. Comparison of SP, LP, MC, and MD demonstrated that the ablation volume was greater when the fiber was in contact with the stone in all pulse modes for both fragmentation and dusting.[24,36] Furthermore, Aldoukhi et al.[24] demonstrated that the MD mode was significantly superior in terms of fragmentation compared with all other pulse modes, even when the stone was contacted. The MD mode was also better than the regular SP mode in low-frequency and energy popcorn settings and showed true noncontact lithotripsy (96% of strikes were indirect vs. 61% for SP in an in vitro model; $p = 0.059$).[37]

The dusting efficiencies of the four different Ho:YAG modes and the fiber-stone distances were also compared. Soft stone models (e.g., uric acid) and hard stone models (e.g., calcium oxalate monohydrate) were laser with 4 kJ of energy delivery at 0.4 J and 70 Hz. When in contact with the stone, MC mode was significantly more effective than SP and LP modes (up to 45% and 56%, respectively), although MD mode was not tested. At 1 mm, MD was the most effective mode ($p < 0.05$) and provided an ablation efficiency equivalent to that of the SP and LP modes in contact with the stone. At 2 mm, there were no significant differences in mean mass loss between the pulse types. In addition, the pulse modulation did not significantly impact the hard stone dusting.[36]

At the time of this review, five clinical studies comparing regular and Moses lithotripsy had been published (Table 1). A nonrandomized and nonblinded trial analyzed 34 procedures (23 using MOSES™ technology, 11 without it) in comparable groups. They reported a subjective reduction in retropulsion and a higher nonstatistical stone fragmentation rate in the Moses group ($p = 0.19$).[31] These findings were similar but statistically significant in the only double-blinded randomized clinical trial: less retropulsion, 32.7% less fragmentation time, and 19.2% less procedure time.[38] The remaining three were retrospective comparative studies. Pietropaolo et al.[39] reported that the Moses group had significantly shorter laser and total procedure time (14.2 vs. 21.1, 51.6, and 82.1 minutes, respectively) and a higher stone-free rate of 97.3% versus 81.6% in the standard group. However, it should be noted that data on mean stone volume or Hounsfield Units (HU) were not provided. Furthermore, it is important to consider that different laser settings were used in each group, with the Moses group using a higher frequency range (20–35 Hz) while the standard Ho:YAG group used a frequency of 12–18 Hz.[39] In contrast, Wang et al.[40] conducted a study with comparable groups in terms of stone volume and HU and used the same laser setting. Their findings revealed significantly shorter laser and operation time along with higher stone fragmentation efficiency when using MOSES™ technology. Notably, comparison of the LP and MC groups showed similar peak powers.[40] Another study found no significant differences.[41] Clinical studies have reported different complication rates.

In summary, it is worth noting that the majority of the reviewed studies were retrospective comparative studies rather than randomized controlled trials (RCTs). Despite this limitation, these studies' findings suggest that MOSES™ lithotripsy may offer potential benefits over standard Ho:YAG lithotripsy, including reduced retropulsion, shorter procedure time, higher stone-free rates, and improved stone fragmentation efficiencies in certain cases. However, limitations such as inconsistent data on stone volume and HU, variability in laser settings across studies, and mixed findings in different studies should be considered. Further research, particularly larger RCTs, is needed to establish the efficacy and safety of MOSES™ lithotripsy in clinical practice with greater certainty.

In terms of cost, Stern and Monga[42] conducted a comprehensive cost-effectiveness analysis of this new technology. Their estimation revealed an additional cost of $292.36 for MOSES™ technology, which decreased to $253.16 for stones larger than 10 mm considering the approximately 35% reduction in laser time observed in prior in vitro studies. They concluded that cost-effectiveness could be further enhanced by reducing the costs of laser fibers and software or by achieving a time reduction exceeding 4 minutes.[42]

Finally, Winship et al.[43] analyzed the security of the new MOSES™ technology concerning environmental temperature increases. Laser lithotripsy produces heat that can induce ureteral injury if the temperature exceeds 43°C. Thermal injuries depend on temperature as well as exposure time. Different energy and frequency settings were tested by evaluating the SP, LP, MC, and MD modes. An LP produces the greatest heat increase in most settings. In contrast, the Moses modes produced the least amount of heat at settings of 10 W or less. Except for the MC at 0.2 J/70 Hz and all pulse modes at 1 J/20 Hz, none of the settings exceeded the safe thermal dose.[43]

Table 1

Details of the clinical studies assessing MOSES™ technology in lithotripsy.

Literature	Study type	Group	Patients	Stone size, mm	Stone volume, mm^3	Hounsfield units	Fiber, μm	Laser settings	Laser time*, min	Operation time, min	Laser energy, kJ	Stone retropulsion grade, Likert scale 0–3	SFE, mm^3/min	SFR, %	Complications (%)
Mullerad et al.[31] (2017)	PS	Regular	11	NA	422.5 (182.2–875.3)	867 (502–1268)	200 365	NA	10 (2.5–15)	NA	6.4 (2.6–11.9)	NA	58.1 (30.8–102.4)	NA	NA
		MOSES™	23	NA	781.9 (180.7–1691.3)	901.5 (553.5–1085)	200 365 550	NA	6 (2.8–13)	NA	4.5 (1.6–16)	NA	95.8 (51.5–177.4)	NA	NA
Ibrahim et al.[38] (2020)	RCT	Regular	36	14 ± 9.7	NA	841 ± 348	200	1 J, 10 Hz (fragmentation)	7.4 ± 5.7	**50.9 ± 27.9**	11.1 ± 20.3	**1 ± 0.68**	NA	83.3%	4 (11.1%)
		MOSES™	36	17 ± 15	NA	991 ± 213		0.4 J, 80 Hz (stone dusting)	6.1 ± 9.8	**41.1 ± 21.1**	10.8 ± 14.1	**0.5 ± 0.45**	NA	88.4%	3 (8.3%)
Pietropaolo et al.[39] (2021)	RS	Regular	38	11.8 ± 4	NA	NA	NA	0.4–0.8 J 12–18 Hz	**21.1 ± 15.1**	**82.1 ± 27**	NA	NA	NA	**81.6%**	5 (13.1%)
		MOSES™	38	10.9 ± 4.4	NA	NA		0.4–0.8 J 20–35 Hz	**14.2 ± 12.3**	**51.6 ± 17.1**	NA	NA	NA	**97.3%**	2 (5.2%)
Wang et al.[40] (2021)	RS	LP	102	12 (10.75–15)	683.47 ± 39.36	993.65 ± 149.58	200	0.3 J, 60 Hz	**5.94 ± 0.96**	**21.17 ± 6.78**	NA	NA	**114.94 (132.06–101.34)**	85.3%	Fever 2.9% ARF 3.9%
		MC	114	12 (10–14)	674.48 ± 41.03	990.43 ± 149.93			**4.99 ± 1.06**	**18.39 ± 5.13**	NA	NA	**137.86 (163.78–114.38)**	86.8%	Fever 3.5% ARF 4.4%
Knoedler et al.[41] (2022)	RS	Regular	66	11.6 ± 9.2	NA	NA	230	0.8 J, 8 Hz	6.7 ± 7.9	39.8 ± 24.6	3.8 ± 4.8	NA	NA	52.3%	6.1%
		MOSES™	110	11.8 ± 7.9	NA	NA		0.4 J, 80 Hz	7.5 ± 11.1	43.5 ± 32.1	5.1 ± 6.7	NA	NA	65.3%	6.4%

In bold, statistically significant results.

* In Ibrahim et al.[38] corresponds to the fragmentation/pulverization time, measuring from starting lasing till the end of lasing including laser pedal pauses.

ARF = acute renal failure; LP = long pulse; MC = Moses contact; NA = not available; PS = prospective study; RCT =: randomized controlled trial; RS = retrospective study; SFE = stone fragmentation efficiency; SFR = stone-free rate.

Table 2

Details of the clinical studies assessing MOSES™ technology in HoLEP.

Literature	Study type	Group	Patients	Prostate size, cm^3	Enucleation laser setting	Hemostasis laser setting	Enucleation time, min	Enucleation efficiency*, g/min	Hemostasis time†, min	Total energy, kJ	↓ Hb, g/dL	↓ Ht, g/dL	Postop complications‡, first 3 m
Whiles et al.[44] (2019)	RS	HoLEP	31	**119**	NA	NA	76.3	**0.92**	NA	115.47	NA	NA	NA
		m-HoLEP	18	**152**	NA	NA	79.1	**1.32**	NA	123.83	NA	NA	NA
Yasser Hussein et al.[45] (2020)	RCT	HoLEP	70	84	2 J, 50 Hz		**30.5**	2.08	5.9	NA	1.01	3.02	NA
		m-HoLEP	70	85			**27.1**	2.36	5.3	NA	0.95	2.89	NA
Large et al.[46] (2020)	RS	HoLEP 550 µm	50	110.5 ± 85.5	2 J, 40 Hz	1 J, 20 Hz	**47.1 ± 17.9**	1.54	**10.6 ± 6.1**	NA	**1.5 ± 1.2**	NA	3 (6%)
		HoLEP 1000 µm	50	118.3 ± 92.4			**41.5 ± 14.6**	1.59	**7.7 ± 5.2**	NA	**1.5 ± 1.6**	NA	4 (8%)
		m-HoLEP 550 µm	52	155.6 ± 50.3		1 J, 20 Hz (MOSES™ disabled)	**40.9 ± 15.1**	1.87	**6.3 ± 4.8**	NA	**1 ± 1.1**	NA	2 (1.3%)
Assmus et al.[47] (2021)	RS	HoLEP	95	107.5 (79.8–129.6)	2 J, 40 Hz	1 J, 20 Hz	44 (28–56)	1.41 (0.95–2.4)	NA	81.1 (64.8–117.8)	0.4 (0–2.2)	NA	6 (6.3%)
		m-HoLEP	93	124.5 (51.8–161.3)			38 (28–55)	1.65 (0.9–2.63)	NA	118.2 (88.7–152.7)	0.75 (0–1.85)	NA	3 (3.2%)
Kavoussi et al.[48] (2021)	RCT	HoLEP	30	153 ± 58	2 J, 20–40 Hz		**80 ± 19**	0.95	**29 ± 15**	143 ± 27	NA	**9 ± 4.6**	4 (13%)
		m-HoLEP	30	131 ± 41			**68 ± 20**	0.95	**19 ± 8**	130 ± 47	NA	**6.4 ± 4.1**	3 (10%)
Klett et al.[49] (2021)	RS	HoLEP	180	89 (65–120)	2 J, 10–50 Hz	1 J, 20 Hz	NA	NA	NA	**86.07**	NA	NA	NA
		m-HoLEP	255	98 (69–124)	2 J, 20 Hz (apex)	1 J, 20 Hz (MOSES™ disabled)	NA	NA	NA	**101.44**	NA	NA	NA
Lee et al.[50] (2021)	RS	HoLEP	120	115.8 (90.4)	2 J, 40 Hz	1 J, 20 Hz	42.9 (17.6)	NA	NA	NA	NA	NA	5 (4.17%)
		m-HoLEP	192	114.8 (73.2)			41.7 (17)	NA	NA	NA	NA	NA	4 (2.08%)
Nevo et al.[51] (2021)	RCT	HoLEP lobe	27	107	2 J, 40 Hz	1.5 J, 30 Hz	50.1 (25)	0.7 (0.54)	**9 (16)**	57.8 (23.3)	NA	NA	4 (1.5%)
		m-HoLEP lobe					45.4 (28.3)	1.1 (0.84)	**4.1 (2)**	55.2 (25.1)	NA	NA	
Nottingham et al.[52] (2021)	RS	HoLEP	50	NA	2 J, 40 Hz	1 J, 20 Hz	47.1 (18)	1.37	**10.6 (6)**	95.9 (39.7)	NA	NA	12 (24%)
		m-HoLEP	54	NA			45.9 (18.8)	1.75	**8.1 (5.9)**	110.4 (47.7)	NA	NA	10 (18.5%)
Rodríguez Socarras et al.[53] (2021)	RS	HoLEP	137	75.77 ± 42.25	2 J, 60 Hz	1 J, 40 Hz	**31.46 ± 14.85**	**2.54 ± 1.31**	**8.35 ± 5.38**	NA	1.73 ± 0.61	NA	13 (9.5%)
		m-HoLEP	80	86.66 ± 50.01			**22.1 ± 9.27**	**4.11 ± 2.41**	**3.01 ± 2.5**	NA	1.53 ± 0.57	NA	2 (2.75%)
Noureldin et al.[54] (2023)	RS	HoLEP	28	115.6 ± 38.5	2 J, 40 Hz	2 J, 20 Hz	**63.4 ± 17.8**	**1.3 ± 0.4**	**7.1 ± 2.6**	**116.7 ± 37.6**	**1.47 ± 0.5**	NA	NA
		m-HoLEP	62	109.5 ± 30.8			**47 ± 12.5**	**1.7 ± 0.6**	**3 ± 1.1**	**84.9 ± 26.9**	**1.07 ± 0.45**	NA	NA

In bold, statistically significant results.

* Calculated from prostate tissue removed and enucleation time in Yasser Hussein et al.[45], Large et al.[46] and Kavoussi et al.[48] studies.

† Corresponds to hemostasis pedal time, instead of the total hemostasis time, in Nevo et al.[51] and Nottingham et al.[52] studies.

‡ In Assmus et al.[47] study, only complications Clavien-Dindo ≥3b are notificated.

HoLEP = holmium enucleation of the prostate; Hb = hemoglobin; Ht = hematocrit; m-HoLEP = MOSES™ HoLEP; NA = not available; RS = retrospective study; RCT = randomized controlled trial.

5. MOSES™ technology in HoLEP

As stated by the manufacturer, the new pulse modulation system offers improved enucleation efficiency (grams of prostatic tissue enucleated per minute) and hemostasis control, allowing for a better view and dissection of the plane with a faster learning curve.[17] While studies have not specifically evaluated the laser-prostate tissue interaction with MOSES™ technology, it has been tested in vitro on the ureteral and bladder wall. Different settings were tested, including 0.4 J/50 Hz and 0.3 J/80 Hz in the ureter and 5 J/5 Hz in the bladder using both regular and Moses modes. Among these settings, only the modulated laser at 0.3 J/80 Hz demonstrated significantly narrower and more precise incisions with reduced collateral coagulation damage compared with the regular mode. No significant differences were observed between the other settings in either mode.[22]

Twelve studies clinically evaluated MOSES™ technology in prostate procedures: 11 in HoLEP (3 RCTs and 8 retrospective comparative reviews; Table 2) and one in holmium laser ablation of the prostate. Among the three published RCTs, only two (Yasser Hussein et al.[45] and Kavoussi et al.[48]) were randomized preoperatively in a 1:1 fashion. Hussein et al. reported the findings of the largest RCT published to date (n = 70 in each arm) in an abstract. Their results showed a statistically significant reduction of 11.1% (3.4 minutes) in enucleation time as well as a decrease in mean laser total time (36.4 vs. 31.5 minutes; $p < 0.01$) and mean laser fiber consumption (3.3 vs. 2; $p < 0.001$) in the m-HoLEP group (HoLEP using MOSES™ technology). However, these improvements did not translate into a reduction in blood loss or hospital stay.[55] In contrast, Kavoussi et al.[48] demonstrated significantly shorter total, enucleation, and hemostasis time. Nonetheless, although the enucleation efficiency was not directly compared, when estimated using the mean prostate size and mean enucleation time, the groups appeared equal. They also reported a smaller change in hematocrit loss in the m-HoLEP group.[48] Finally, Nevo et al.[51] randomized right lobe enucleation using MOSES™ technology and left lobe enucleation using standard Ho:YAG, or vice versa, performed by 2 expert surgeons and 2 trainees. They noted a higher enucleation efficiency (1.75 vs. 1.05 g/min; $p = 0.05$) in the expert versus trainee group. They also found less fiber degradation in all groups, indicating better control of the fiber and incision sharpness with MOSES™ technology.[51]

In retrospective studies, MOSES™ technology also seemed to reduce enucleation time. Large et al.[46] reported a significant mean reduction of 13.2% (6.2 minutes), Rodríguez Socarras et al.[53] reported 29.7% (9.3 minutes), and Noureldin et al.[54] reported 25.9% (16.4 minutes).[46,53,54] This improvement in enucleation time led to increased enucleation efficiency, although with some heterogeneity (17%–61.2%). In addition, hemostasis control was faster with the new technology in some studies (23.6%–63.9%). Nonetheless, it is important to note that Large et al.,[46] despite showing a 40.6% faster hemostasis time in the m-HoLEP group, disabled the MOSES™ technology. Klett et al.[49] also disabled the MOSES™ technology, and although their hemostasis time was not reported, they used more total energy during surgery in the Moses group (86.07 vs. 101.44 kJ; $p < 0.001$). Three additional studies used more energy during m-HoLEP than HoLEP.[44,47,52] Noureldin et al.[54] was the only group to demonstrate a significant reduction in energy use with MOSES™ technology (116.7 vs. 84.9 kJ; $p < 0.001$). In terms of blood loss, Large et al. (1.5 vs. 1 g/dL; $p = 0.02$), Rodríguez Socarras et al.[53] (1.73 vs. 1.53 g/dL; $p = 0.372$), and Noureldin et al.[54] (1.47 vs. 1.07 g/dL; $p < 0.001$) reported a slight but lesser reduction in hemoglobin levels in the Moses group. In contrast, Assmus et al.[47] reported slightly greater blood loss in m-HoLEP patients (0.4 vs. 0.75 g/dL; $p = 0.45$). No significant differences in complications were observed in any of the studies, and no significant differences were observed among the studies that analyzed functional outcomes. Finally, m-HoLEP associated with same-day discharge was cost-effective, with hospital savings of $840 per case for the initial surgical episode compared with HoLEP with no same-day discharge.[48] Simultaneously, MOSES™ technology in holmium laser ablation of the prostate showed better ablation efficiency in small to medium prostates, saving 12 minutes of operating room time for 50 g of prostate.[56]

In summary, the use of MOSES™ technology in HoLEP seems to reduce enucleation and hemostasis time, leading to improved enucleation efficiency. However, minimal changes in hemoglobin or hematocrit levels do not translate into clinical changes. Despite these improvements, no differences were observed in postoperative complications or functional outcomes. Therefore, considering these findings and the potential economic benefits highlighted by Lee et al.,[50] patients who undergo standard HoLEP can be discharged like m-HoLEP patients.

6. Conclusions

The Moses effect is an inherent physical phenomenon in lasers with wavelengths close to the water absorption peak. This gives the Ho:YAG laser a versatility that increases with pulse-length modifications and pulse modulation technologies such as MOSES™. The MOSES™ technology in lithotripsy showed promising preclinical results, and while clinical studies suggest potential benefits such as reduced retropulsion, shorter procedure time, higher stone-free rates, and improved stone fragmentation efficiency; limitations in data consistency, laser settings, and mixed findings across studies warrant caution. MOSES™ technology in HoLEP seems to reduce enucleation and hemostasis time, leading to improved enucleation efficiency. However, there were minimal changes in hemoglobin or hematocrit levels and no significant differences in complications or functional outcomes. Further research, including larger RCTs, is needed to fully evaluate the benefits and limitations of MOSES™ technology in clinical practice.

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Statement of ethics

Not applicable.

Conflict of interest statement

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Data availability

The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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