Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.
Vol. 67, 1, pp. 85–88, Bucarest, 2022

**Génie biomédicale**

# APPLICATION OF LASER TECHNOLOGY IN URINARY STONE TREATMENT

VICTOR CAUNI[1], BOGDAN MIHAI[1], FLORIN TANASE[2], CRISTAN PERSU[2], CIOFU IRINA[2]

**Key words: Laser, Lithotripsy, Holmium YAG Laser, Thulium fiber laser.**

**Ureteroscopy with laser lithotripsy is now the main surgical treatment option for most patients with urinary stones. Holmium laser is still considered the gold standard for laser lithotripsy. In this review, we will discuss the characteristics of different lasers and their use in lithotripsy while trying to identify the next potential lasers suitable for laser lithotripsy.**

## 1. INTRODUCTION

In the last decade the global trend for the treatment of renal stones showed an increasing role for semirigid and flexible ureteroscopy (retrograde intrarenal surgery or RIRS), a relative stable indication for percutaneous nephrolithotomy (PCNL) and a decline for shockwave lithotripsy (SWL) and open-surgery [1–3]. The main reasons for this tendency are the rapid improvement of endoscopic and laser technology, the durability of the new flexible scopes, introduction of robotic surgery and combined URS and PCNL surgery (endoscopic combined intrarenal surgery or ECIRS) [4].

The modern interventional approach for urinary stones is now the ureteroscopy with laser lithotripsy in both EU and the USA. In the last decade, the number of patients treated in the USA using this procedure has risen to up to 300,000 per year [5].

Laser induced shock waves have many medical applications such as lithotripsy, photodisruption and nanosurgery.

Theodore Maiman constructed the first working laser in 1960 and it was a ruby laser pumped with a flash lamp. Once the ruby laser was invented, urinary stones treatment included laser lithotripsy technology. Ruby lasers were used for applications demanding higher energies as they can generate very high pump powers. The procedure was not that efficient because the pulse power of this type of laser was uncontrollable. The next type of laser used was the carbon dioxide (CO2) laser, but this method was less successful because it was not equipped with fiber optic systems.

These laser types worked in continuous-wave mode, but the efficacy was lower due to thermal damage that affected the surrounding soft tissues and the absence of fiber optic technology systems [6].

The first lasers who solved the problem with pulse control and a fiber optic delivery system were the Nd:YAG lasers (Neodymium: Yytrium-Alumunium-Garnet). Laser crystals play the role of active gain medium (lasing medium) in solid-state lasers. They are used to generate the output of a laser by various pumping techniques. The Nd:YAG laser is now being used in various medical specialties. It uses continuous wave, pulsed and Q-switched technologies. However, the Q-switched mode used for endoscopic lithotripsy in the urology field has limitations - the nanosecond pulses can only be delivered by inflexible optical fibers with core diameters of at least 400 μm [7].

The Nd:YAG lasers were replaced by Ho:YAG (Holmium:Yytrium-Alumunium-Garnet) lasers who had superior performance and a high success rate and becoming the preferred laser for lithotripsy. The Ho:YAG technology uses rare Holmium ions doped in a YAG crystal. This is very efficient when dealing with urinary stone fragmentation. When tuned to water absorption wavelengths, the main component in the human body, it has successful medical applications such as tissue heating and cutting. It is highly effective in cardiology, dermatology, ophthalmology, and especially in urology, where it has been used for the last three decades starting with animal models [8].

In this paper, we will review different lasers, their characteristics and importance in urological lithotripsy, the latest technological developments and the next potential lasers used in this medical field.

## 2. MATERIAL AND METHODS

We reviewed the available papers on currently used lasers for lithotripsy in urology. We used as search terms ‘lithotripsy’, “Holmium laser” and‘ Thulium fiber laser’. Only original papers were considered eligible.

## 3. RESULTS AND DISCUSSIONS

### HOLMIUM LASER

The Holmium laser has several advantages for lithotripsy: it can fragment any urinary stone no matter its chemical composition into small stone particles [9], it delivers the energy with minimal waste through thin and flexible fiber, and the tissues are minimally penetrated and damaged due to the water that absorbs this wavelength used by the laser [10,11].

Laser lithotripsy can be achieved either by a plasma-mediated interaction (photoacoustic mechanism) or a thermal-mediated interaction (photothermal mechanism). In a plasma-mediated interaction on the stone surface tiny bubbles of plasma are produced when the laser is active. This process creates mechanical shock waves that will eventually fragment the stone into smaller pieces. The stone can be fragmented by mechanical shocks generated by laser pulses with short duration, of less than 10 μs. In the thermal mediated interaction, the stone will heat up to initiate thermochemical reactions until the point it brakes. Pulses with duration of more than 10 μs generate little acoustic waves but significantly rise the temperature where applied. Thus, the stone is removed by either of evaporation, melting, thermomechanical tension, and/or chemical decomposition

[1] Colentina Clinical Hospital, Department of Urology
[2] Carol Davila” University of Medicine and Pharmacy, Dept. of Urology, Bucharest, Romania

[12]. Based on the photothermal mechanism, maximizing the energy transfers by absorption from laser to stone results in the most efficient stone destruction. Water cavitation within the pores of kidney stones (termed microexplosions) is also a significant contributor to stone damage [13,14].

Holmium-YAG lasers use a thermal-mediated interaction. In the field of urology, Holmium lasers can also be used for prostate resection or incision of urethral strictures.

Recently developed Holmium lasers have multiple adjustable parameters that increase the efficiency of stone destruction. One can adjust the pulse energy (PE), the frequency (Fr) and the pulse duration (PD). Along with these parameters there are also other characteristics that ensure the efficacy of the procedure, such as the power and the wavelength generated by the laser, and the optical, mechanical, and chemical structure of the stones involved.

The pulse energy (PE) measures the optical energy generated for each pulse and it ranges between 0.2 and 6.0 J. During ureteroscopy, surgeons usually opt for 0.6 to 2.0 J, but the energy should be adapted to stone particularities, such as location, hardness, and dimensions. A high PE will create more fragmentation and is used often fora hard stones while a low PE is used in dusting techniques for creating very small fragments that will evacuate with the urinary floe. The pulsed energy leads to evaporation of fluids and expansion, generating a vapor bubble. In the event of bubble disintegration, the stone fragments can change position; the effect is known as retropulsion and is directly proportional to PE specifications [15].

The frequency (Fr) of the pulses generated are calculated per second, so it is measured in Hertz. High frequency settings can produce faster fragmentation especially with a low PE setting. Because combinations of high PE and high Fr can lead to higher retropulsion, the procedure is usually done using low Fr16.

Pulse duration (PD) measures the exact duration of each optical pulse generated in microseconds. The classic Holmium devices use short pulses of 150-350 µs; the latest devices provide long pulses as well, of up to 1200 µs, that generate the same amount of energy but on a longer term. Although it seems the are no differences in fragmentation time between these two settings, LP setting decreases retropulsion and fiber-tip degradation [17,18]. However, in both instances the energy is delivered in a single pulse and is partly wasted because of vapor channel formation. Newer devices have pulse modulation technology that generates a first pulse responsible for the vapor channel formation, while the second one concentrates the rest of the energy for stone fragmentation [17]. This mode is also known to as 'Moses Tec' because the laser-induced vapor channel created during the initial pulse effectively 'parts the wat e (the Moses Effect in the field of laser–tissue interactions), making the second pulse more effective [19,20].

The holmium:YAG laser is effective on all stone types and is cost-effective, so it has become the gold standard for laser lithotripsy. Several characteristics make it suitable for urological applications – its wavelength of 2,100 nm is absorbed by water; the energy delivery system uses standard optical fibers and the flashlamp pumping system has lower costs than other comparable devices. The holmium laser combines characteristics of both erbium:YAG laser, that cuts tissues with its 2,940 nm wavelength, and neodymium:YAG laser, that thermally coagulates and achieves hemostasis with its 1,064 nm wavelength [21].

The flexibility and small size of laser fibers made the laser lithotripsy the main fragmentation method associated with modern ureteroscopes [22]. The development of smaller semirigid and flexible scopes and the advances in fiber optic and digital technology led to the development of miniaturized laser fibers. In the present days flexible ureteroscopy associated with Holmium - laser lithotripsy is currently the gold standard because it can be used to treat all types of urinary calculi. Nevertheless, this technology is not perfect; some of the drawbacks include the lack of matching the wavelength's water absorption peak with that of the tissues and the inability to couple high power in fiber cores smaller than 200 µm [23].

The development of high-power (100 – 120 W) holmium lasers for lithotripsy has raised concerns about the high temperatures capable of thermal tissue injury due to direct infrared energy absorption and the subsequent overheating of the saline [24,25].

Holmium laser's safety profile is very good compared to other lithotripsy sources because the 2100-nm wavelength of the Ho:YAG laser permits rapid absorption in water and limits the tissue injury. However, complications after ureteroscopy with laser lithotripsy can occur. Ureteral stricture after ureteroscopy ranges between 1–4% [26]. This can be due to the biothermal effects caused by the resulting heat that leads to injury of the ureteral wall [27,28].

In the last years high-frequency multiple cavity Holmium:YAG lasers have been developed for laser lithotripsy because the stone dusting techniques for flexible ureteroscopy require high frequency and low-pulse energy settings [29,30]. Although the high power multiple-cavity Holmium:YAG lasers have been developed for effective tissue ablation (enucleation of the prostate) no study so far has been able to provide significant advantage of high-power Holmium generators over low-power generators for laser lithotripsy.

Various studies have confirmed a significant temperature rise can occur around the fiber tip and once it exceeds the 43 °C threshold it can cause tissue injury, which will lead eventually to ureteral stricture [31].

## THULIUM FIBER LASER (TFL)

Thulium:YAG lasers, a different device than the thulium fiber laser, emerged as an alternative to the holmium device for prostate enucleation [32]. It is a solid-state laser that uses 2,010 nm wavelengths. The thulium fiber laser is a silica fiber, long and 10-20 µm thin that is doped with thulium ions. Diode lasers excite the ions; laser beams have wavelengths of 1.940 nm and function in continuous or pulsed mode. The 1.940 nm wavelength closely matches the near-infrared absorption peak of water at 22 ˚C [33].

Fiber lasers are a new addition to the devices used for lithotripsy. They usually deploy silica fibers doped with ytterbium, erbium and thulium and generate wavelengths that range from 1.075 nm to 1.550 nm and 1.940 nm. Unlike the erbium:YAG, holmium:YAG and thulium:YAG lasers, they do not use utilize solid-state crystals, but regular silica fibers that are chemically doped. Once the light is generated inside a small fiber, another diode laser pumps it to reach a final surgical fiber, that is made of silica and is conveniently disposable. This technology couples the advantages of high-power delivery with suitable compact fiber cores [34]. Silica fibers have good thermal, chemical, mechanical, and biocompatible characteristics, which make them reliable for transmission of high laser power for lithotripsy, can be used inside the small working channel of flexible ureteroscopes, and they have corrosion resistance [35]. Using wavelengths close to water absorption peaks in tissues, this technology ensures that the prompt rise in temperature targets only superficial tissues, without affecting any profound structures. These advantages place the TFL on a superior rung in lithotripsy technology when compared to the holmium laser.

Hardy L.A. *et al*. in 2019 showed 60 % of stones treated with TFL are completely fragmented in ≤ 5 min compared to only 7 % stones treated with a holmium laser [36]. Compared to the Ho:YAG laser, the TFL achieved twice the ablation volume [37].

It seems that beside the energy that the stone absorbs directly, the stone destruction process is highly influenced by the absorption of infrared energy by water molecules [38]. The TFL achieves an absorption rate for the energy generated superior to that of its alternatives, the thalium:YAG and the holmium:YAG lasers – two times, respectively four times higher [39]. This allows the TFL to deploy up to four times lower pulse energy than the holmium laser [40].

The main mechanism of laser lithotripsy for TFL is composed by two sequences – first a rapid heating of water molecules that surround the stone forming a compressed vapor cavity responsible for shockwaves that fragment the stone and the second – the water contained in the stone structure expands due to the heating created from laser energy, which leads to high pressure and stone destruction [41,42].

The TFL requires less heat dissipation and can operate with high-power and high-frequency settings with simple fan ventilation inside the generator compared to water-cooled Holmium:YAG lasers [34]. In the last years the TFL power has increased up to 500 W and remained cost competitive. TFL is a promising alternative for laser lithotripsy with a very good stone ablation rate and possibile lower complications than Holmium Laser.

The performance of both TFL and the holmium laser have been compared in various studies, using equivalent parameters for impartial comparison. The results showed the superiority of the TFL used for lithotripsy techniques; it achieved faster ablation times (two to four times) and less retropulsion of the stone in dusting and fragmentation modes [11,43,44]. Whether the TFL will become the new gold standard in laser lithotripsy remains to be determined.

ERBIUM LASER

The Erbium:YAG laser is a flashlamp-pumped solid-state laser that has been introduced as a possible alternative to the holmium laser for lithotripsy [45,46]. While the performance of the Er:YAG laser for lithotripsy seems to be superior to that of the Ho:YAG laser, it poses challenges with its fiber-optic delivery system. The wavelengths of 2.940 nm that it generates are more convenient than the 2.120 nm of the holmium laser in terms of water absorption rates; however, finding the right materials has proven difficult since silica loses its transparency properties beyond 2.700 nm. Alternatives have been found using germanium oxide or fluoride fibers, but these have their own limitations in terms of higher prices and lower flexibility [47–49].

ULTRASHORT PULSE FEMTOSECOND LASERS

The high interest in developing this technology is explained by its ultraprecise performance that is not influenced by parameters such as laser wavelength or optical characteristics of tissues[50]. However, this technology is still highly expensive compared to the holmium:YAG, has no suitable fiber delivery system and no clinical use at this point in time.

## 3. CONCLUSIONS

The Holmium:YAG laser is the gold standard for laser lithotripsy during ureteroscopy. Although it served the field of laser lithotripsy in urology for 30 years now this technology has several technical limitations. It remains to be seen if it will be replaced by TFL as the new gold standard.

*Received on February 10, 2022*

REFERENCES


1. A. Pietropaolo, S. Proietti, R. Geraghty, et al., *Trends of urolithiasis: interventions, simulation, and laser technology ʾover the last 16 years (2000–2015) as published in the literature (PubMed): a systematic review from European section of Uro-technology (ESUT)*. World J. Urol. **35,** pp. 1651–8165 (2017).
2. O.A. Raheem, Y.S. Khandwala, R.L. Sur, K.R. Ghani, J.D. Denstedt, *Burden of urolithiasis: trends in prevalence, treatments, and costs*, Eur. Urol. Focus, **3**, pp. 18–26 (2017).
3. ****Trends in Upper Tract Stone Disease in England: Evidence from the Hospital Episodes Statistics Database*, Urol Int. **98**, *4*, pp. 391-396 (2017).
4. J.K.M. Li, J.Y.C Teoh, C.-F. Ng, *Updates in endourological management of urolithiasis International*, J. of Urology, **26**, pp. 172-183 (2019).
5. D.T. Oberlin, A.S. Flum, L. Bachrach, R.S Matulewicz, S.C. Flury, *Contemporary surgical trends in the management of upper tract calculi*, J. Urol., **193**, *3*, pp. 880-884 (2015).
6. Dretler, S. P. Laser lithotripsy: a review of 20 years of research and clinical applications. *Lasers Surg. Med.* **8**, 341–356 (1988).
7. E. Steiger, *The Nd:YAG-laser in laser-lithotripsy: possibilities and limitations due to system performance*, in: Waidelich W., Waidelich R. (eds) Laser/Optoelektronik in der Medizin / Laser/Optoelectronics in Medicine. Springer, Berlin, Heidelberg (1990).
8. D.E. Johnson, D.M. Cromeens, R.E. Price, *Use of the holmium:YAG laser in urology*, Lasers Surg. Med., **12**, *4*, pp. 353–363 (1992).
9. J.M. Teichman, G.J. Vassar, J.T. Bishoff, G.C. Bellman. *Holmium:YAG Lithotripsy yields smaller fragments than litho- clast, pulsed dye laser or electrohydraulic lithotripsy*, J. Urol. **159**, *1*, pp. 17–23 (1998).
10. P. Kronenberg, O. Traxer, *Update on lasers in urology 2014: current assessment on holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripter settings and laser fibers*, World J. Urol., **33,** *4*, pp. 463–469 (2015)
11. O. Traxer, E.X. Keller, *Thulium fiber laser: the new player for kidney stone treatment? A comparison with Holmium:YAG laser*, World J. Urol., **38, pp.** 1883–1894 (2020).
12. A.J. Welch, H.W. Kang, H. Lee, J.M. Teichman, *Calculus fragmentation in laser lithotripsy*, Minerva Urol. Nefrol., **56**, pp. 49–63 (2004).
13. N.M. Fried, *Recent advances in infrared laser lithotripsy*, Biomed. Opt. Express, **9**, pp. 4552–4568 (2018).
14. L.A. Hardy, P.B. Irby, N.M. Fried, in *Scanning Electron Microscopy of Real And Artificial Kidney Stones Before and After Thulium Fiber Laser Ablation in Air and Water*, SPIE BiOS: Therapeutics and Diagnostics in Urology (10468, 104680G); SPIE, 2018.
15. J. Sea, L.M. Jonat, B.H. Chew, J. Qiu, B. Wang, J. Hoopman J, *et al*., *Optimal power settings for Holmium:YAG lithotripsy*, J. Urol., **187**, pp. 914–919 (2012).
16. J. Tracey, G. Gagin, D. Morhardt, J. Hollingsworth, K.R. Ghani, *Ureteroscopic high-frequency dusting utilizing a 120-W holmium laser*, J. Endourol., **32**, pp. 290–295 (2018).
17. A.H. Aldoukhi, W.W. Roberts, T.L. Hall, K.R. Ghani, *Watch your distance: the role of laser fiber working distance on fragmentation when altering pulse width or modulation*, J. Endourol., **33**, pp. 120–126 (2018).
18. H.W. Kang, H. Lee, J.M. Teichman, J. Oh, J. Kim, A.J. Welch, *Dependence of calculus retropulsion on pulse duration during Ho: YAG laser lithotripsy*, Lasers Surg. Med., **38**, pp. 762–72 (2006).

19. M.M. Elhilali, S. Badaan, A. Ibrahim, S. Andonian, *Use of the Moses technology to improve holmium laser lithotripsy outcomes: a preclinical study*, J. Endourol., **31**, pp. 598–604 (2017).
20. A. Vogel, V. Venugopalan, *Mechanisms of pulsed laser ablation of biological tissues*, Chem. Rev., **103**, pp. 577–644 (2003).
21. Welch, A. J., van Gemert, M. J. C., Star, W. M. & Wilson, B. C. in *Optical-Thermal Response of Laser-Irradiated Tissue* (eds. A.J. Welch, M.J.C. van Gemert), pp. 27–64, Springer, 1995.
22. C.D. Scales Jr., T.L. Krupski, L.H. Curtis, *et al*., *Practice variation in the surgical management of urinary lithiasis,* J. Urol., **186**, *1*, pp. 146-150 (2011).
23. N.M. Fried, P.B. Irby, *Advances in laser technology and fiber-optic delivery systems in lithotripsy*, Nat. Rev. Urol., **15**, pp. 563–573 (2018).
24. W.R. Molina, *et al*., *Influence of saline on temperature profile of laser lithotripsy activation*, J. Endourol., **29**, pp. 235–239 (2015).
25. D.A. Wollin, *et al*., *Effect of laser settings and irrigation rates on ureteral temperature during holmium laser lithotripsy, an in vitro model*, J. Endourol. **32**, pp. 59–63 (2018).
26. P.C. May, R.S. Hsi, H. Tran, M.L. Stoller, B.H. Chew, T. Chi *et al*., *The morbidity of ureteral strictures in patients with prior ureteroscopic stone surgery: multi- institutional outcomes*, J. Endourol., **32**, *4*, pp. 309-314 (2018).
27. D.A. Wollin, E.C. Carlos, W.R. Tom, W.N. Simmons, G.M. Preminger, M.E. Lipkin, *Effect of laser settings and irrigation rates on ureteral temperature during holmium laser lithotripsy, an in vitro model*, J. Endourol., **32**, *1*, pp. 59-63 (2018).
28. A.D. Maxwell, B. MacConaghy, J.D. Harper, A.H. Aldoukhi, T.L. Hall, W.W. Roberts, *Simulation of laser lithotripsy-induced heating in the urinary tract*, J. Endourol., **33**, *2*, pp. 113-119 (2019).
29. A.H. Aldoukhi, W.W. Roberts, T.L. Hall, K.R. *Ghani Holmium Laser Lithotripsy in the new stone age: dust or bust?* Front. Surg., **4**, *57* (2017)
30. B.R Matlaga, B. Chew, B. Eisner, M. Humphreys, B. Knudsen, A. Krambeck, D. Lange, M. Lipkin, N.L. Miller, M. Monga, V. Pais, R.L. Sur, O. Shah, *Ureteroscopic laser lithotripsy: a review of dusting vs fragmentation with extraction*, *J. Endourol*., **32**, 1, pp. 1–6 (2018).
31. B. Winship, D. Wollin, E. Carlos, C. Peters, J. Li, R. Terry, *et al.*, *The rise and fall of high temperatures during ureteroscopic holmium laser lithotripsy*, J. Endourol., **33**, *10*, pp. 794-799 (2019).
32. S.J. Xia, *et al.*, *Thulium laser versus standard transurethral resection of the prostate: a randomized prospective trial Eur. Urol.* **53**, 382–389 (2008).
33. E.D. Jasen, T.G. van Leeuwen, M. Motamedi, C. Borst, A.J. Welch, *Temperature dependence of the absorption coeffi- cient of water for midinfrared laser radiation*, Lasers Surg. Med., **14**, *3*, pp. 258–268 (1994).
34. S.D. Jackson, A. Lauto, *Diode-pumped fiber lasers: a new clinical tool?* Lasers Surg. Med., **30**, pp. 184–190 (2002).
35. J.A. Harrington, *Infrared fibers, and their applications*, SPIE (2004).
36. L.A. Hardy, V. Vinnichenko, N.M. Fried, *High power holmium:YAG versus thulium fiber laser treatment of kidney stones in dusting mode: Ablation rate and fragment size studies*, Lasers Surg. Med., *51*, pp. 522–530 (2019).
37. S. Poletajew, B. Braticevici, A. Brisuda, *et al*., *Timing of radical cystectomy in Central Europe – multicenter study on factors influencing the time from diagnosis to radical treatment of bladder cancer patients*, Cent. European J. Urol., **68**, *1*, pp. 9-14 (2015).
38. A. Roggan, U. Bindig, W. Wäsche, F. Zgoda, *Action Mechanisms of Laser Radiation in Biological Tissues* (eds. H.P. Berlien, G.J. Muller), **87**, Springer, 2003.
39. G.M. Hale, M.R. Querry, *Optical constants of water in the 200 nm to 200 μm wavelength region*, Appl. Opt., **12**, pp. 555–563 (1973).
40. R.L. Blackmon, P.B. Irby, N.M. Fried, *Comparison of holmium:YAG and thulium fiber laser lithotripsy: ablation thresholds, ablation rates, and retropulsion effects*, J. Biomed. Opt., **16**, 071403 (2011).
41. R. de La Floratos, *Lasers in urology*, BJU Int., **1999**, *84*, pp. 204–211.
42. J. Lee, T.R.J. Gianduzzo, *Advances in laser technology in urology*, Urol. Clin. N. Am., **2009**, *36*, pp. 189–198.
43. V. Cauni, B. Mihai, F. Tanase, I. Ciofu, C. Persu, Percutaneous Nephrolithtotomy Lithotripsy: The role of Ballistic and Ultrasonic Energy, Rev. Roum. Sci. Techn.– Électrotechn. et Énerg., **66**, *3*, pp. 207–209, (2021).
44. R.H. Shin, *et al.*, *Evaluation of a novel ball tip holmium laser fiber: impact on ureteroscope performance and fragmentation efficiency*, J. Endourol., **30**, pp. 189–194 (2016).
45. K.F. Chan, *et al*., *Erbium:YAG laser lithotripsy mechanism*, J. Urol., **168**, pp. 436–441 (2002).
46. H. Lee, H.W. Kang, J.M. Teichman, J. Oh, A.J. Welch, *Urinary calculus fragmentation during Ho:YAG and Er:YAG lithotripsy*, Lasers Surg. Med., **38**, pp. 39–51 (2006).
47. N.M. Fried, *Potential applications of the erbium:YAG laser in endourology*, J. Endourol., **15**, pp. 889–894 (2001).
48. J. Qiu, *et al*., *Comparison of fluoride and sapphire optical fibers for Er:YAG laser lithotripsy*, J. Biophotonics, **3**, pp. 277–283 (2010).
49. J. Raif, M. Vardi, O. Nahlieli, I. Gannot, *An Er:YAG laser endoscopic fiber delivery system for lithotripsy of salivary gland stones*, Lasers Surg. Med., **38**, pp. 580–587 (2006).
50. J. Qui, *et al*., *Femtosecond laser lithotripsy: feasibility and ablation mechanism*, J. Biomed. Opt., **15**, 028001 (2010).