Fragmentation Devices: Lithotripters, Lasers and Other Advances

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6.1 Introduction

In mini percutaneous nephrolithotomy (mini-PCNL), after gaining safe access into the pelvicalyceal system (PCS), renal stones are ablated by intracorporeal lithotripsy (ICL). ICL during miniPCNL can be done effectively using fragmentation devices like lithotripters and lasers [1]. Paralleling the advancement in miniaturization of nephroscopes during the past few decades, a significant development in the fragmentation devices has also taken place. ICL involves either smash and extract or smash and go techniques. Smash and extract technique involves breaking larger stones into smaller stone fragments and then extracting them out of the PCS. During miniPCNL these stone fragments can be retrieved via the smaller sized percutaneous tract passively with the vacuum cleaner effect, actively with saline flushing of stone fragments using the ureteric catheter or by applying active suction to innovative mini nephroscope sheaths like shah sheath or clear petra systems (Well Lead Medical Co., Ltd., China) [2]. Stone fragments can also be retrieved using stone grasping forceps and baskets. Smash and go technique involves ablating the larger stone into fine stone dust without the need for using forceps or baskets. The stone dust automatically gets cleared due to saline irrigation or active suction or if left will be cleared up spontaneously in the postoperative period. During miniPCNL as the size of the percutaneous tract is smaller, majority of the endourologists prefer to dust the major bulk of the stone using various fragmentation devices (lithotripters and lasers) and then clear the smaller residual stone fragments left at the end for achieving complete stone clearance.

6.2 Lithotripters

Various intracorporeal lithotripters were invented for ablating the renal stones since the inception of PCNL. These lithotripters differ based on the type of energy source like electro hydraulic, pneumatic and ultrasonic lithotripsy [3, 4]. Recently newer generation lithotripters have been developed, which use combination of ballistic and ultrasonic energies for better and faster fragmentation of renal stones.

6.2.1 Electro Hydraulic Lithotripters (EHL)

These were the first intracorporeal lithotripters introduced in 1955 for treating bladder stones that were subsequently extended to breaking ureteric and renal stones as well. They work by the genera-

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tion of spark between two electrodes leading to the formation of a cavitation bubble. Collapse of this bubble generates a shock wave that helps in fragmentation of the stones. Significant retropulsion of the stone and tissue perforation are the drawbacks of this modality [5]. Because of this, use of EHL is hardly ever practiced in modern-day practice for treating renal stones.

6.2.2 Mechanical or Ballistic Lithotripters

These lithotripters work similarly to a jackhammer where the projectile inside the hand piece is accelerated either using electromagnetic energy or pneumatic energy (compressed air). Pneumatic lithotripters are the most commonly used mechanical lithotripter device for breaking renal stones. Using compressed air, ballistic energy is generated which gets transferred onto a metallic probe which further breaks the stone like a hammer and chisel effect. It breaks all types of stones irrespective of their composition but stone fragments generated are larger which have to be manually retrieved. The probe vibrates longitudinally either in single or multiple pulses [6]. The Swiss Lithoclast®(Electro medical systems, EMS) was first introduced in 1991 which was further improvised in 2005, Swiss Lithoclast® 2(Electro Medical Systems, EMS) with better fragmentation and lesser pushback effect. The lithoclast probes come in various sizes and lengths for use in standard PCNL, miniPCNL, and semirigid ureteroscopic surgery. Probes specifically designed for use in miniPCNL are smaller in size ranging from 0.8 mm to 2 mm. Recently, flexible pneumatic probes of size 0.89 mm and length 600–940 mm were also introduced for use in retrograde intrarenal surgery (RIRS). During PCNL both the frequency and the air pressure can be adjusted according to the hardness of the stone for optimal fragmentation. The major disadvantage of pneumatic lithotripters is a significant amount of retropulsion and also bleeding due to friction between the stone and the pelvicalyceal mucosa while breaking the stones.

6.2.3 Ultrasonic Lithotripters

These lithotripters convert electrical energy into mechanical energy with the help of piezo ceramic elements. A very high frequency of 20,000 Hz will be transmitted to the probe which helps in breaking the stone into smaller fragments and also generation of fine dust. This high-frequency oscillations can lead to generation of heat, which might risk damaging the scopes. Hence continuous cooling of the generator is achieved by continuous saline irrigation and also suctioning. Simultaneous suctioning helps in the clearance of stone fragments and stone dust at a faster speed leading to decreased operation times. Isolated ultrasonic lithotripters are not commonly used in day-to-day practice. Lithotripters with both pneumatic and ultrasonic energy facilities have been shown to be having superior efficiency than used alone in stone fragmentation [7]. Examples of such lithotripters include Swiss Lithoclast® Master/Ultra (EMS, Switzerland), Swiss Lithoclast® Select TM(EMS), and Calcuson Lithotripter® (Karl Storz). Swiss Lithoclast® Master, as shown in Fig. 6.1, has a facility for both pneumatic and ultrasonic lithotripters. Special handpieces such as Vario for ultrasonic lithotripsy and PN3 handpiece for pneumatic lithotripsy are used. For combined use of pneumatic and ultrasonic energy compatible solid pneumatic probes are available which pass inside

Fig. 6.1 Swiss Lithoclast® Master (EMS) having combined pneumatic and ultrasonic lithotripter facility. Also depicted in the figure are three handpieces from above downward (Vario handpiece, PN3 handpiece and combined)

Fig. 6.2 Showing newer generation dual-energy lithotripters (**a**) Shock Pulse Stone Eliminator™ (Olympus, Japan); (**b**) Swiss Lithoclast®Triology (EMS, Switzerland)

the hollow ultrasonic probes. The ultrasound probes are of larger diameter (3.3–3.8 mm), have added facility of suctioning and are generally used in standard PCNL. They cannot be passed through a 12 Fr mini nephroscope with a working channel of 6Fr. However, recently ultrasound probes of size less than 2 mm have been introduced for use in miniPCNL. Xiong et al. have designed a Micro Ultrasonic probe (HuifuKangCo.Ltd., China) of size 2 mm, which combines the high efficiency of ultrasonic lithotripsy while retaining the ability to pass through mini nephroscopes as well [8]. CyberWand™ (Gyrus ACMI, Southborough, MA, USA) is another fixed dual-probe lithotripter where the inner ultrasonic probe vibrates at 21000 Hz with suction and the outer probe (size 3.3 and 3.8 mm) vibrates at 1000 Hz. However, this cannot be passed through mini nephroscope due to larger size of the probe. Retropulsion is significantly less with ultrasonic lithotripters but they are not effective in hard stones.

6.2.4 New Generation Dual Lithotripters

Lithotripters like Swiss Lithoclast® Master or CyberWand™ have double probes (inner and outer probes) for providing both pneumatic and ultrasonic energies for fragmenting and suctioning of stone fragments. Newer generation dual-energy lithotripters with single probes were developed with better fragmentation/dusting and faster stone clearance rates. These include Shock Pulse Stone Eliminator™ (Olympus, Japan) and Swiss Lithoclast®Triology (EMS) (Fig. 6.2). They have single lumen probes with larger inner lumen compared to dual-probe lithotripters leading to better suctioning of even larger stone fragments without the need for active removal of stone fragments. Both these lithotripters have plug and play facility and have handpiece to which single lumen probes of various sizes are attached for use in standard or miniPCNL and ureteroscopic surgery (URS). Effective and variable suction facility with these lithotripters greatly reduces the operating times.

Shock Pulse Stone Eliminator™ simultaneously delivers constant ultrasonic energy with intermittent high-frequency bursts (as high as 300 Hz) of ballistic or mechanical energy for fragmenting as well as aspirating renal stones (Fig. 6.3) [9]. Standard and high power modes buttons are provided on the handpiece for use, according to the hardness of the stone. Single and reusable probes are available with this equipment. For use in miniPCNL, a single or reusable 1.83 mm probe of length 418 mm is available.

Swiss Lithoclast®Triology delivers electromagnetically generated impact and ultrasonic energy along with suction capability. Unlike Shock Pulse, in Lithoclast®Triology there is an option to use either ultrasonic or mechanical or both energies. Pistol grip handpiece and integrated active cooling mechanism for handpiece are also available (Fig. 6.4). Stone catcher with integrated suction facility minimizes the risk of clogging of single lumen probes and also helps in collecting stone dust or fragments for stone analysis. For use in miniPCNL, probe sizes 1.1, 1.5, and 1.9 mm are available. However, the probes

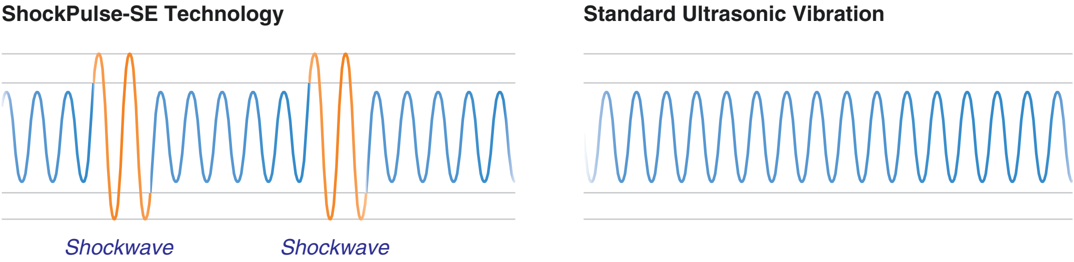


Fig. 6.3 Mechanism of generation of constant ultrasonic energy with intermittent high-frequency ballistic pulses in Shock Pulse Stone Eliminator™ (Olympus, Japan) when compared to standard ultrasonic vibration

Fig. 6.4 (**a**) Handpiece used in Shock Pulse Stone Eliminator™ (Olympus, Japan) with surgeon controls; (**b**) Pistol grip handpiece used in Swiss Lithoclast®Triology (EMS, Switzerland) without any surgeon control buttons on it

used in Lithoclast®Triology are disposable for single use, thus adding to increased cost of treatment. Lithoclast®Triology has been shown to be faster than Shock pulse in in vitro studies due to 16 times more ultrasonic probe tip displacement (0.041 mm Vs 0.0025 mm), greater tip displacement during impact or function (0.25 mm Vs 0.01 mm) and larger probe tip diameter [10, 11] (Table 6.1).

6.2.5 Cordless Lithotripters

For ease of use and portability, handheld lithotripters were also developed. The Stone Breaker™ (Laryngeal mask airway company Switzerland; distributed by COOK Medical, Bloomington, IN) is a cordless handheld lithotripter that generates ballistic energy using a compressed carbon dioxide cartridge. Lithobreaker®(EMS) is an electrokinetic handheld lithotripter that works using four AAA batteries. Probe sizes of 1 mm and 2 mm are available for use in PCNL as well as URS. These lithotripters have shown to be as effective as conventional lithotripters [12].

6.3 Lasers

Laser energy devices are the most versatile lithotripters available. Developed over a period of 6 decades, a lot of research has gone into optimization of type of laser and laser settings for both soft tissue ablation and for stone fragmentation [13]. Lasers providing pulsed mode are best suited for lithotripsy as compared to continuous mode lasers, which are better suited for soft tissue ablation [14].

Holmium: YAG laser is the most commonly used laser for lithotripsy and is the current gold standard for laser intracorporeal lithotripsy (ICL) [15]. Modes commonly used in miniPCNL are dusting and fragmentation. In case of fragmentation as mentioned earlier the vacuum cleaner

Table 6.1 Various Lithotripters of use during miniPCNL

S. No.	Lithotripter	Probe type	Available probe sizes
1.	Swiss Lithoclast® 2 (EMS)	Pneumatic probe	0.8 mm × 410 mm 1.3 mm × 410 mm 2.0 mm × 425 mm
2.	Swiss Lithoclast® Master(EMS)	Ultrasound probe Combination of pneumatic with ultrasound probe in miniPCNL	1.5 mm × 573 mm 1.9 mm × 360 mm Not available
3.	Swiss Lithoclast®Triology (EMS)	Combined pneumatic and ultrasound single-use probes	1.5 mm × 440 mm (5Fr) 1.9 mm × 341 mm (6Fr)
4.	Shock Pulse Stone Eliminator™ (Olympus)	Combined pneumatic and ultrasound single and reusable probes	1.83 mm × 440 mm(5.5Fr)

EMS, Electro Medical Systems; PCNL, Percutaneous nephrolithotomy

effect in addition to the use of forceps/baskets for active removal of fragments is used [16]. Moses effect which improves the transmission of laser energy through water is the latest advancement in Ho:YAG laser [17, 18]. The Thulium Fiber laser is another emerging diode-based laser that provides new options to treat stone disease [19].

The laser provides a range of techniques of lithotripsy that include dusting, fragmentation, popcorning and pop-dusting [13, 17]. The modulation of pulse energy, pulse frequency and pulse width provide this wide range of modes of lithotripsy while using laser technology. These aspects of laser lithotripsy in the perspective of mini-PCNL are discussed in the following section.

6.3.1 Settings of Laser and Lasing Techniques

The Ho: YAG laser provides a wide range of settings for power output. Based upon the permutation and combination in frequency, energy and pulse width the laser can be used to dust the stone, to fragment it into small pieces or to create a popcorn effect [20]. Fragmentation and dusting are two most commonly used lithotripsy techniques in miniPCNL.

Dusting is carried out at low energy, high-frequency settings (0.2–0.5 J × 20–80 Hz) [21]. Dusting although a little time consuming creates powder of sub-centimetric size of the stone, which does not require active removal. On the other hand, fragmentation entails the use of higher energy, low frequency and shorter pulse width so as to create fragments, which require active removal (08–1.2 J × 6–10 Hz). Pinning the stone against the wall of the calyx helps in fragmentation of stone safely. The removal of fragments is most commonly done using Bernoulli's principle or the Vacuum Cleaner effect [16]. The stone fragments themselves migrate along the sheath with the eddy current formation. The use of a small fibered laser also helps in continued irrigation to create this effect. The other methods of fragment retrieval include the use of suction, forceps and baskets for stone retrieval. The exit strategies may also be determined by the modality or the technique used for lithotripsy in addition to the stone size and achievement of complete stone clearance.

Devices such as lithAssist (Cook Medical, Bloomington, IN) and laser suction handpiece devices are handheld devices tailor-made to suck fragments created by laser [22]. LithAssist has a 11.6 Fr dual lumen stainless steel cannula for suction with a 5 Fr coaxial inner lumen to allow passage of Laser fiber. In contrast to this device, the laser suction handpiece device has a 12 Fr lumen for suction and a separate working channel for laser fiber [23]. These devices have helped in extending the use of laser lithotripsy to bigger stones including staghorn stones.

6.3.2 Laser Fiber

Laser fiber is a particularly important determinant of the laser lithotripsy technique. In contrast to flexible ureteroscopy, a larger diameter fiber is preferred for miniPCNL (300 or 550/600 microns). Large diameter fibers help in using higher energies and cause lesser retropulsion as compared to smaller fibers [24]. On the other hand, small fiber allows for irrigation fluid to egress easily through the sheath, thus improving the vision, efficiency and operating times. The smallest caliber laser fibers (100 microns) are available with Thulium Fiber laser as compared to Ho-YAG where the smallest fiber diameter available is 200 microns only [25]. This is much advantageous with miniaturized version of PCNL.

Ball tip laser fibers have been proposed to provide easy insertion in scopes and also prevent damage to flexible scopes. However, the ball tip degrades due to burn back effect within a few seconds of surgery. Thus, this effect is useful in the setting of single-use fibers. The single-use fibers have been claimed to decrease the overall cost of procedure [26]. There has been much ado about whether the fiber's outer cladding should be stripped or not. The advantages and disadvantages of both are highlighted in Table 6.2. Optimal use of laser fiber is extremely important to obtain the optimal outcome at the same time preventing damage to scopes and operation room (OR) staff as discussed later.

6.3.3 Newer Advances in Lasers

6.3.3.1 Moses Effect and Moses Technology

Moses effect is a phenomenon of deformation of the surface of a diamagnetic liquid by application of a magnetic field [27]. As mentioned in the Old testament, Moses crossed the red sea and divided the water holding his staff as the Israelites crossed the sea [28]. Similarly, the Holmium laser, which is absorbed by water due to its properties, creates a vapor tunnel parting the "Sea" of water and blood. Moses technology capitalizes on this principle by using 2 consecutive pulses (Figs. 6.5 and 6.6a) [29]. The first pulse imparts the energy to create a vapor bubble while the second wave travels through this bubble to cause maximal effect over the stone. There are both in vitro and in vivo studies comparing Moses technology to Standard Ho:YAG pulse mode for URS as well as its efficacy for miniPCNL [30, 31]. It has shown to decrease retropulsion and consequently a reduction in procedure duration in preclinical studies [18]. However, cost and single manufacturer remains a drawback for its wider adoption.

6.3.3.2 Thulium Fiber Laser

Thulium Fiber laser (TFL) has been called so as the energy is generated in a chemically doped small fiber and has a wavelength of 1940 nm (Fig. 6.6b) [32]. The wavelength provides a high absorption peak in water and is hence proposed to have better fragmentation properties with almost 1.5 to 4 times faster ablation of stone [33]. Further, it can be easily coupled with smaller fibers with diameter as low as 100 microns. This helps in easy maneuverability and better irrigation while doing lithotripsy.

6.3.4 Laser Vs. Other Modalities for miniPCNL—Head to Head Comparison

Tangal et al. and Ganesamoni et al. have compared Laser versus ballistic lithotripsy [34, 35]. The fragmentation time, stone-free rates and complications were comparable between both the groups. However, Ganesamoni et al. found higher stone migration, higher use of forceps for stone retrieval and difficult fragment retrieval when using ballistics [35]. Tangal et al. in addition had a combined group in which the operative time was found to be significantly shorter than either of the groups [34]. They stated that it is better to fragment large size stones using ballistic to around a size of 1 cm each and then use laser for either dusting or fragmentation to smaller pieces, which can be retrieved easily. In a comparative study by Akbulut et al. on laser vs ultrasonic lithotripter, they found that there was higher stone-free rate in laser group as compared to ultrasonic group although it did not reach statistical significance. They further found laser to be much cost effective as compared to ultrasonic lithotripter [36].

Table 6.2 Summary of the advances or technical aspects of laser lithotripsy[a]

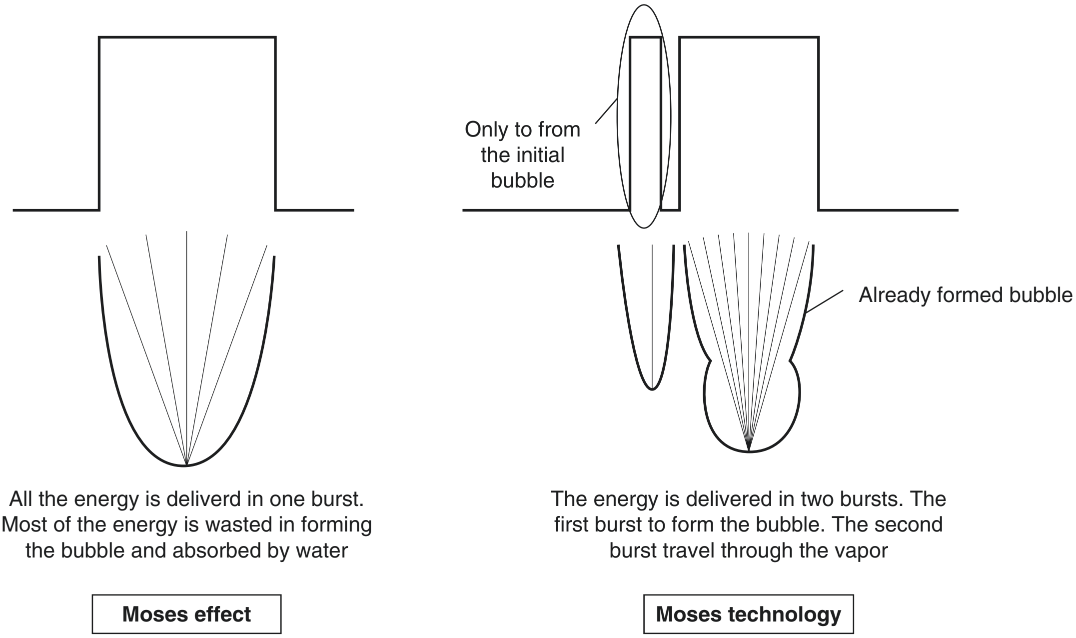
Laser Parameter	Technical aspect	Benefit	Verdict
Laser settings and Technique	Fragmentation	Faster ablation of primary stone Fragments removed using vacuum cleaner effect	Excellent technique
	Dusting	Sub centimetric powdered fragments • No need for active removal	Ablation itself takes more time, compensated by other time gains • Ultra-high-frequency lithotripters further Shorten surgical time
	Pop Corning & Pop Dusting	Ideal for multiple smaller stone Fragments in an enclosed space such as calyx Avoids endless chase of fragments	Helpful technique, complementing other Lithotripsy methods
Laser lithotripter	Long pulse length (pulse duration or pulse width)	• Less fiber tip degradation • Less stone retropulsion • Smaller residual fragments • Ideal for "dusting"	Gradual rise in its use
	Moses effect (modulated laser pulse)	More ablative (in vitro) • Less retropulsion	No significant difference between lasingand procedural time in vivoSingle manufacturer) • Cost is an issue
	Thulium fiber laser	More ablative than Ho:YAG • Less retropulsion Coupled with small fiber	Limited availability Lack of randomized trials
Laser fibers	Ball tip fiber	Easier insertion in deflected scope	Initial benefit lost after a few seconds with degradation
	Tip cleaving tools	All were equivalent	Simple scissors are equally effective
	Coated fiber	Greater stone ablation • Easier to pass in the scope • Safer than stripped fiber	More advantageous than stripped fibersin several categories
	Stripping of fibers	Debatable higher stone ablation	Significantly less advantages than coated Fibers

[a] Adapted from Kronenberg P et al. Curr Urol Rep. 2018 (13)

6.3.5 Complication and Safety Concerns

The complications of miniPCNL using laser lithotripsy are no different from the use of any other intracorporeal lithotripsy technique. The complications such as bleeding and infection are more related to the surgical procedure itself rather than the use of laser ICL [37]. In fact, in one of the recent studies from our center we found no difference in clinically significant blood loss or infection rate in standard vs miniPCNL [38]. Thus, these common complications and few others such as pelvicalyceal injury, pleural injury, solid organ injury, or bowel injury are more related to access rather than the type of lithotripsy used.

However, unique to Laser lithotripsy is safety concerns for OR staff and surgeons associated with its use in OR. The eyes remain the most vulnerable organ, which can be damaged by laser, especially when it is brought in very close con-



All the energy is deliverd in one burst. Most of the energy is wasted in forming the bubble and absorbed by water

The energy is delivered in two bursts. The first burst to form the bubble. The second burst travel through the vapor

Fig. 6.5 Moses effect and Moses Technology for Ho:YAG laser (From: Aldoukhi AH, Black KM, Ghani KR. Emerging Laser Techniques for the Management of Stones. Urol Clin North Am. 2019 May;46(2):193–205)

Fig. 6.6 Laser Generators (**a**) Moses™ Technology from Lumenis™ Pulse (Yokneam, Israel). (**b**) Thulium Fiber Lasers from Quanta™ (Samarate, Italy) and Intercardia Life Sciences™ (Delhi, India)

tact to the eye without any protective covering for the eyes. Simple eyeglasses are equally effective as special Laser protective glasses [39]. The eye injury is a zero event and has never been reported in literature yet.

Another important collateral damage of laser energy is to delicate scopes used in endourology. It is more common for flexible scopes used during URS or RIRS rather than to the rigid scopes used in miniPCNL. Still, the laser fiber should be kept in vision at all times, especially when activating the laser. The fiber should be kept at an adequate distance from the optical end of the scope [40]. Other recommendations include keeping the fiber tip covered and regular cleaving of fiber.

6.4 Other Advances

To overcome the high complication rate because of the generated shockwaves with EHL, a newer lithotripter named nanosecond electro pulse lithotripter (NEPL) (Urolith-105 M device) was developed by Lithotech Medical Ltd. (Israel). It produces electric pulses of high voltage being discharged in nanosecond duration, which gets transferred onto the stone. This generates tensile thermomechanical stress in the stone leading to fragmentation of stone. NEPL was found to be better than EHL in an in vitro study by Martov et al. [41]. Martov et al. also have shown in another in vitro study that NEPL was more effective and requires significantly less energy and time for stone disintegration than holmium laser [42]. Flexible probes of various sizes 2.7 to 4.5 Fr are available for use with cystoscope, semirigid ureteroscope, and flexible ureteroscopes [43]. Studies done using this technology in miniPCNL are not available so far in the existing literature.

6.5 Conclusions

Miniaturization of fragmentation devices has accompanied the miniaturization of PCNL procedure. Currently Ho:YAG Laser remains the gold standard for stone ablation in miniPCNL. Moses technology and Thulium Fiber laser are showing promising results in terms of faster stone ablation. Newer generation lithotripters with thin probes are tailor-made to decrease retropulation and are being combined with effective suction mechanism for a better clearance rate.

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