Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.
Vol. **66**, *3*, pp. 207–209, Bucarest, 2021

PERCUTANEOUS NEPHROLITHOTOMY LITHOTRIPSY: THE ROLE OF BALLISTIC AND ULTRASONIC ENERGY

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

Key words: Ultrasonic lithotripsy, Ballistic lithotripsy, Percutaneous nephrolithotomy (PCNL).

The medical industry is in continuous search for improved techniques aimed at helping medical professionals treat urinary stones more effectively. When it comes to stones disintegration, several sources of energy are available, but two of them imposed as being the most effective: ballistic and ultrasonic. The aim of our paper is to review the literature in search for current evidence regarding the usage and limits of these sources of energy. We reviewed the latest papers on currently used devices for PCNL lithotripsy. We used as search terms "lithotripsy", "ballistic lithotripsy" and "ultrasonic lithotripsy", "combined lithotripsy". Only original papers were considered eligible.

1. INTRODUCTION

Fernström and Johansson described first percutaneous nephrolithotomy (PCNL) in 1976 as a technique of removing kidney stones through a percutaneous tract [1]. In the next years, this procedure was further developed by many urologists that established this as a routinely used technique [2–4]. With time, PCNL helped by new technologies for stone fragmentation managed to replace open surgery for kidney stones, being superior of the second in terms of morbidity, costs, and patient recovery. Being more and more used PCNL required better stone fragmentation and stone removal devices.

Stone lithotripsy is required in PCNL because in approximatively all cases stones are bigger that nephrostomy tract. There are 4 major lithotripsy techniques: electrohydraulic lithotripsy (EHL), laser lithotripsy, ultrasonic lithotripsy, and ballistic lithotripsy.

Yutkin invented EHL in 1955 at the University of Kiev, being the first technique used for intracorporeal lithotripsy. The EHL probe in composed of two insulated electrodes with different voltage polarities. If a large enough voltage difference is applied to the electrodes, the insulation can be overcome, and a spark can be produced. This discharge leads to formation of plasma, and water that surrounds the electrode is vaporized. This in term produces a shockwave and a cavitation bubble which impacts the stone. It takes only 1/800 seconds since current is applied to shockwave. The shockwave's power depends on the voltage and charge that are applied. This electrohydraulic technique was mostly used for ureteroscopy rather than PCNL. Laser lithotripsy is mostly used for flexible and rigid ureteroscopy, and in the last years for miniaturized PCNL. Ballistic and ultrasonic lithotripsy remain gold standard techniques for stone fragmentation in PCNL. Newer devices deliver both ballistic and ultrasonic energy on a single probe.

Ballistic lithotripsy is achieved by using the energy generated by a moving probe. The movement of the probe is induced by different types of stimuli, depending on the manufacturer: large-scale compressed air, handheld high-pressure CO_2 cartridges, or electromagnetic acceleration of a magnetic core. The close contact between the probe and the stone and the subsequent transfer of ballistic energy can fragment the stone like a jackhammer. No heat is generated during the lithotripsy. The probe is solid so it can be used only with rigid or semirigid endoscopes. This ballistic technique was first introduced in 1900s by Swiss Lithoclast. The metal projectile in the handpiece of the LithoClast is propelled by measured bursts of compressed air against the head of a metal probe at a frequency of 12 Hz and a pressure of 3 atmospheres. Control of the device is achieved with the use of foot pedals once the probe is in contact with the stone [5]. The control unit of the Swiss Lithoclast allows for modulation of the pulse frequency, adjusting the pulse count and pneumatic pressure, and controlling the duty-cycle in a range of 10 to 100 %. It can be used in single shot mode or in continuous firing (which is mostly used). During ballistic lithotripsy with continuous firing stone is fragmented in small pieces that can be extracted with baskets. The best way to fragment the stone is by fixing it between the urothelium and the ballistic probe, thus preventing migration. Ballistic lithotripsy is most useful for large, hard stones.

Breaking renal stones by using ultrasonic vibration has been reported since 1953, achieved by Mulvaney, but extending its applications to ureteral conditions only occurred during the 1970s and 1980s [6, 7]. The mechanism of action in the ultrasound probe implies multiple physical phenomena. A piezoceramic plate in the transducer is excited by electrical currents produced by a high-frequency generator. The excited piezoceramic crystal oscillates between expansion and contraction, resulting in a vibratory energy at a frequency up to 27 kHz. The resulting energy is transmitted along either a solid or a hollow probe and is converted into vibrations of the tip (horizontal or transverse). Through contact with the stone, the tip produces a drill effect and subsequent stone fragmentation. The fragmentation is achieved strictly through the mechanic effect, while other effects such as heat, cavitation or shock waves are negligible [8, 9]. The risk of collateral damage to tissues such as the urothelial mucosa is minimal; while these tissues can be exposed to the mechanical energy of the probe, they tend to be compliant and not resonate with the vibrational energy [10]. Most of the devices use a hollow probe in combination with a suction device. By activating the suction device, the irrigation solution and small stone fragments are evacuated in a container. This also helps in cooling the instrument. Multiple sizes of ultrasonic probes are available, to fit various requirements.

[1] Colentina Clinical Hospital, Department of Urology
[2] Carol Davila" University of Medicine and Pharmacy, Dept. of Urology, Bucharest, Romania
* Corresponding author: Cristian Persu, E-mail: drcpersu@gmail.com

Depending on the needs, sizes available range from 2.5 to 12 Fr. Stone characteristics influence the time required for complete disintegration. Dimensions, density, and the exterior aspect of the stone play a greater role than its chemical composition, with rough or small stones being destroyed easier.

Newer devices for PCNL lithotripsy combine ballistic and ultrasonic energy in two probes but in later years a new type of device appeared, which combines both types of energy in a single probe. The first such type of compound device on the market was the Lithoclast Ultra, comprised of two different handpieces with a connection that allowed joining both the ultrasonic and the pneumatic elements. It consists of an ultrasonic, piezoelectrically-driven handle, and a solid probe, but it can also accommodate a pneumatic probe that is inserted coaxially to the latter. Both modes of operation can be activated individually or at the same time.

These two principles of operation complement each other: the ultrasonic probe transmits energy by directly impacting the stone, and, when required, the ballistic probe can be activated to provide additional ballistic fragmentation by extending past the range of the ultrasonic probe. If the ballistic probe is retracted, the ultrasonic fragmentation can resume.

2. **MATERIAL AND METHODS**

We reviewed the latest papers on currently used devices for PCNL lithotripsy. We used as search terms 'lithotripsy', "ballistic lithotripsy" and 'ultrasonic lithotripsy", "combined lithotripsy". Only original papers were considered eligible.

3. **RESULTS AND DISCUSSIONS**

3.1. BALLISTIC LITHOTRIPSY

The first clinical report which demonstrated the utility and safety of Swiss Lithoclast was conducted by Languetin and colleagues in 1990 for treating stones located at all levels of the urinary tract [11].

In 2000, Yinghao *et al.* achieved stone-free rates (SFRs) of 55 % at 1 month and 78 % at 2 months on 145 patients who underwent ureteroscopy [12].

The Canadian StoneBreaker trial compared LMA StoneBreaker™ and the Swiss Lithoclast® in a randomized controlled trial (RCT) for stone fragmenting during percutaneous nephrolithotripsy. The results reported by Chew et al. in 2011 showed that StoneBreaker™ had an easier setup and shorter times in both stone fragmentation and total lithotripsy time. Stone free rates were no different between the devices [13].

In 2017 a randomized clinical trial was conducted by M.H. Radfar to compare ballistic lithotripsy and ultrasonic lithotripsy in PNCL. Results showed shorter fragmentation and removal time (SFRT) using pneumatic technology when dealing with harder stones and ultrasonic technology for the softer ones. Overall, there were no significant differences in SFRT, stone free rate, hospital stay and postoperative complications [14].

In 2021, B.K. Yadav published the results of a randomized comparative study comparing ultrasonic and ballistic lithotripsy in percutaneous nephrolithotomy conducted on 119 patients. The stone-free rates were similar, 78.69 % and 74.13 %, respectively. Mean stone fragmentation time was shorter for ultrasonic lithotripsy, but complication rate was similar [15].

3.2. ULTRASONIC LITHOTRIPSY

Following the reports of ultrasonic lithotripsy usage for staghorn calculi by Kurth and colleagues, the ultrasound technology has become widely used and highly regarded in percutaneous renal stone surgery [16]. Liatsikos and colleagues [17] compared the efficacy of several intracorporeal ultrasonic lithotrites using plasters of Paris stone phantoms immersed in water and continuous irrigation. A rigid nephroscope was used in all cases. When comparing the Storz ultrasound (Calcuson 27610020, Karl Storz) with Wolf (2270004), the Circon ACMI (USL 2000) and the Olympus LUS, the Storz device had the lowest stone fragmentation time. A helpful requirement of the study would have been pressure standardizing.

Kuo and colleagues tried to standardize the test between different devices by applying constant force on the stone. The Olympus LUS-2 (Olympus, Inc., Melville, NY), Circon-ACMI USL-2000, Karl Storz Calcuson, Olympus LUS-1, and the Richard Wolf model 2271004 were compared; the first two had the lowest time of stone fragmentation [18].

UreTron is the latest device using ultrasonic lithotripsy and provides precise control of the probe vibration (UreTron). In a non-randomized, prospective comparison with CyberWand™, StoneBreaker™, and Swiss LithoClast Select™, the UreTron lithotripter achieved the highest stone clearance rate (59 mm^2/min) [19].

3.3. COMBINED DUAL-PROBE LITHOTRIPSY (BALLISTIC AND ULTRASONIC)

First in vitro studies shown high efficiency of stone fragmentation using the combination pneumatic/ultrasonic lithotrite. Faster mean time of phantom stone fragmentation were reported compared with ultrasound alone and pneumatic alone lithotrites (7.41 min *vs.* 12.87 min *vs.* 23.76 min), by Auge *et al*. The same results were obtained by Olbert and colleagues. Lehman et al. performed a randomized control trial comparing a combined ultrasonic and ballistic lithotripter (Swiss Lithoclast® Master) with a standard ultrasonic lithotripter in PCNL. Combined mode had a shorter fragmentation time for the hard stones. The soft stones were fragmented faster by the ultrasound lithotripter. Complication rate, stone free-rate and operation time was similar in both groups [20–22].

Another multicenter RCT that compared CyberWand™ (combined dual-probe lithotripter) with ultrasonic lithotripter (Olympus LUS-II), found no difference stone-free rates, complications, or intervention time. There were more malfunctions with combined lithotripter than ultrasonic lithotripter [23]. York NE conducted a RCT in which 3 lithotripters were compared, two with dual energy (CyberWand™, Lithoclast Select), and LMA™ StoneBreaker which is a pneumatic device. Stone free rates were similar for stones > 2 cm, with the same efficiency and safety for all the devices [24].

3.4. COMBINED SINGLE PROBE LITHOTRIPSY (ULTRASONIC AND BALLISTIC)

The Olympus ShockPulse™ was the first device approved by FDA in 2014, having a single combined probe for delivery of both energy types. The system relies on constant ultrasonic operation with intermittent ballistic pulses. The device is controlled with foot pedals or with digital buttons. Its probes are larger than in ultrasonic-only devices and it is also equipped with a vacuum device. In vitro studies showed superiority of the single probe compared with dual probe in stone fragmentation time and fragments evacuation [25], most likely due to the single probe having a larger lumen, while in dual probe most of the lumen being occupied by the ballistic probe. Another device delivering ballistic (electromagnetic) and ultrasonic energy through a single probe is the Swiss Lithoclast Trilogy® (EMS), approved in 2018. The lithotripsy operation and the suction capabilities are controlled by a pedal. The first published paper of in-vitro results using begostone phantom calculi showed the superiority of LithoClast Trilogy in comparison with ShockPulse-SE and LithoClast Select [26]. Another newer evaluation between different lithotripsy devices on artificial stones showed that Trilogy was more efficient [27]. Sabnis *et al.* reported stone-free rates of 93 % immediately post-operatively and 96 % at 1-month on imaging, using Trilogy [28]. Nottingham et al reported stone free rates of 67 % for LithoClast Trilogy with a stone clearance rate of 68.9 mm^2/min [29]. On animal tissue Trilogy was safe to use, complication rates in the studies being reduced [28 – 30].

4. CONCLUSIONS

PCNL is the gold standard treatment for renal stones higher than 2 cm, but with higher rates of complications comparing with ureteroscopy. Since shorter operation time reduces complication rates, lithotripsy devices are constantly improving. Ultrasonic and ballistic lithotripsy remain the most used techniques, having been proven safe and efficient. Newer devices combining both energy in dual-probes or single probes aim to decrease intervention time, maintaining same safety levels.

Received on May 27, 2021

REFERENCES

1. I. Fernstrom, B. Johansson, Percutaneous *pyelolithotomy. A new extraction technique*, Scand J Urol Nephrol **10**, pp. 257–259 (1976).
2. P. Alken, G. Hutschenreiter, R. Gunther, M. Marberger Percutaneous stone manipulation, J Urol, **125**, pp. 463–466 (1981).
3. J.E. Wickham, M.J. Kellet. Percutaneous nephrolithotomy, Br Med J (Clin Res Ed), **283**, 6306, pp. 1571–2 (1981).
4. R. V. Clayman, V. Surya, *et al.*, *Percutaneous Nephrolithotomy: Extraction of Renal and Ureteral Calculi from 100 Patients*, The Journal of Urology, **131**, *5*, pp. 868–871 (1984).
5. J. D. Denstedt, P. M. Eberwein, R. R. Singh, *The Swiss Lithoclast: A New Device for Intracorporeal Lithotripsy*, The Journal of Urology, **148**, *3*, Part 2, pp. 1088–1090 (1992).
6. W.P. Mulvaney, *Attempted disintegration of calculi by ultrasonic vibrations*, J Urol, **70**, *5*, pp.*704–707* (1953).
7. M. Chetan, A.M. Morega, *Personal data network for outpatient medical monitoring devices*, Rev. Rou. Sci. Tech., **53**, *3*, pp. 339–348 (2008).
8. P.H. Lange, *Diagnostic and therapeutic urologic instrumentation*, In: P.C. Walsh, R.F. Gittes, A.D. Perlmutter *et al*, editors. Campbell's urology, 5th ed. Philadelphia: W.B. Saunders, pp. 510–40, 1986.
9. M. Marberger, *Disintegration of renal and ureteral calculi with ultrasound*, The Journal of Urology, **131**, *5*, pp. 1023–1024 (1984).
10. J. Grocela, S.P. Dretler, *Intracorporeal lithotripsy: instrumentation and development*, Urol Clin North Am, **24**, pp. 13–23 (1997).
11. J.M. Languetin, P. Jichlinski, R. Favre, W. von Niederhausern, *The Swiss Lithoclast [Abstract]*, J Urol, **143**, *179* (1990).
12. S. Yinghao, W. Linhui, Q. Songxi *et al*, *Treatment of urinary calculi with ureteroscopy and Swiss lithoclast pneumatic lithotripter: report of 150 cases*, J Endourol, **14**, pp. 281–283 (2000).
13. B.H. Chew, O. Arsovska, D. Lange *et al.*, *The Canadian StoneBreaker trial: a randomized, multicenter trial comparing the LMA StoneBreaker and the Swiss LithoClast(R) during percutaneous nephrolithotripsy*, J Endourol, **25**, pp. 1415–1419 (2011).
14. M.H. Radfar, A. Basiri, A. Nouralizadeh *et al.*, *Comparing the Efficacy and Safety of Ultrasonic Versus Pneumatic Lithotripsy in Percutaneous Nephrolithotomy: A Randomized Clinical Trial*, European Urology Focus, **3**, *1*, pp. 82–88 (2017).
15. B.K. Yadav, R.B. Basnet, A. Shrestha, P.M. Shrestha, *Comparison between shockpulse and pneumatic lithotripsy in percutaneous nephrolithotomy,* World J Urol., **39**, *3*, pp. 915–919 (2021).
16. K.H. Kurth, R. Hohenfellner, J.E. Altwein, Ultrasound litholapaxy of a staghorn calculus, J Urol,**117**, *2*, pp. 242–243 (1977).
17. E.N. Liatsikos, C.Z. Dinlenc, J.D. Fogarty *et al.*, *Efficiency and efficacy of different intracorporeal ultrasonic lithotripsy units on a synthetic stone model*, J Endourol,**15**, p. 925 (2001).
18. R.L. Kuo, R.F. Paterson, T.M. Siqueira Jr. *et al.*, *In vitro assessment of ultrasonic lithotripters*, J Urol, **170**, p. 1101 (2003).
19. M.S. Borofsky, M.M. El Tayeb, J.E. Paonessa, J.E. Lingeman, I*nitial experience and comparative efcacy of the UreTron: a new intracorporeal ultrasonic lithotripter*, Urology, **85**, pp. 1279–1283 (2015).
20. Auge BK, Lallas CD, Pietrow PK *et al.*, *In vitro comparison of standard ultrasound and pneumatic lithotrites with a new combination intracorporeal lithotripsy device*, Urology, **60**, 1, pp. 28–32 (2002).
21. P. Olbert, J. Weber, A. Hegele *et al.*, *Combining Lithoclast and ultrasound power in one device for percutaneous nephrolithotomy: in vitro results of a novel and highly effective technology*, Urology, **61**, *1*, pp. 55–59 (2003).
22. D.S. Lehman, G.W. Hruby, C. Phillips *et al.*, *Prospective randomized comparison of a combined ultrasonic and pneumatic lithotrite with a standard ultrasonic lithotrite for percutaneous nephrolithotomy*, J Endourol, **22**, pp. 285–289 (2008).
23. A.E. Krambeck, N.L. Miller, M.R. Humphreys *et al.*, *Randomized controlled, multicentre clinical trial comparing a dualprobe ultrasonic lithotrite with a single-probe lithotrite for percutaneous nephrolithotomy*, BJU Int, 107, pp.824–828 (2011).
24. N.E. York, M.S. Borofsky, B.H. Chew *et al.*, *Randomized controlled trial comparing three diferent modalities of lithotrites for intracorporeal lithotripsy in percutaneous nephrolithotomy*, J Endourol, **31**, pp. 1145–1151 (2017).
25. B.H. Chew, A.A. Matteliano, T. de Los Reyes *et al.*, *Benchtop and initial clinical evaluation of the ShockPulse stone eliminator in percutaneous nephrolithotomy,* J Endourol, **31**, pp.191–197 (2017).
26. EC Carlos, DA Wollin, BB Winship, R Jiang, D Radvak, BH Chew *et al.*, In Vitro Comparison of a Novel Single Probe Dual-Energy Lithotripter to Current Devices, J Endourol., **32**, *6*, pp. 534–540 (2018).
27. M.J. Bader, M. Eisel, F. Strittmatter, U. Nagele, C.G. Stief, T. Pongratz *et al.*, *Comparison of stone elimination capacity and drilling speed of endoscopic clearance lithotripsy devices*, World J Urol., **39**, *3* (2021).
28. R.B. Sabnis, S.S. Balaji, P.L. Sonawane, R. Sharma, M. Vijayakumar, AG Singh *et al.*, EMS Lithoclast TrilogyTM: an effective single-probe dual-energy lithotripter for mini and standard PCNL, World J Urol., **38**, *4*, pp. 1043–50 (2020).
29. C.U. Nottingham, T. Large, K. Cobb, R.L. Sur, N.E. Canvasser, C.L. Stoughton e*t al.*, *Initial Clinical Experience with Swiss LithoClast Trilogy During Percutaneous Nephrolithotomy*, J Endourol., **34**, *2*, pp.151–5 (2020).
30. W. Khoder, F. Strittmatter, A. Alghamdi, M. Seitz, C. Stief, M.J. Bader, *Comparative evaluation of tissue damage induced by ultrasound and impact dual-mode endoscopic lithotripsy versus conventional single-mode ultrasound lithotripsy*, World J Urol., **38**, *4*, pp. 1051–5 (2020).