Original Article

Use of artificial stones in training and laboratory studies, have we found the right material? Outcomes of a systematic review from the European School of Urology

Panagiotis Kallidonis[1], Angelis Peteinaris[1], Domenico Veneziano[2,3], Amelia Pietropaolo[4], Konstantinos Pagonis[1], Constantinos Adamou[1], Athanasios Vagionis[1], Abdulrahman Al-Aown[5], Evangelos Liatsikos[1,6], Bhaskar Somani[4]

[1]Department of Urology, University Hospital of Rion, Patras, Greece, [2]Department of Urology and Kidney Transplant, Grande Ospedale Metropolitano, Reggio Calabria, Italy, [3]School of Medicine, Hofstra Northwell University, New York, USA, [4]Department of Urology, University Hospital Southampton NHS Foundation Trust, Southampton, UK, [5]Department of Urology, Armed Forces Hospital Southern Region, Khamis Mushait, Saudi Arabia, [6]Medical University of Vienna, Vienna, Austria

Abstract

Objective: In this review, we investigated the current literature to find out which artificial stones (AS) are available in endourology, and in which experimental and training schemes they are used.

Materials and Methods: A systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement. Twenty-one out of 346 studies met our inclusion criteria and are presented in the current review. The inclusion criteria were the existence of AS and their use for laboratory and training studies.

Results: There is a wide variety of materials used for the creation of AS. BegoStone powder (BEGO USA, Lincoln, Rhode Island) and plaster of Paris™ were used in most of the studies. In addition, Ultracal-30 (U. S. Gypsum, Chicago, IL) was also used. Other materials that were used as phantoms were AS created from plaster (Limbs and Things, UK), standardized artificial polygonal stone material (Chaton 1028, PP13, Jet 280; Swarovski), model stones consisting of spheres of activated aluminum (BASF SE, Ludwigshafen am Rhein, Deutschland), Orthoprint (Zhermack, Badia Polesine, Italy), and a combination of plaster of Paris, Portland cement, and Velmix (calcium sulfate powder). Many experimental settings have been conducted with the use of AS. Our research demonstrated nine studies regarding testing and comparison of holmium: yttrium–aluminum–garnet laser devices, techniques, and settings. Six studies were about extracorporeal shock wave lithotripsy testing and settings. Three experiments looked into treatment with percutaneous nephrolithotomy. Additionally, one study each investigated imaging perioperatively for endourological interventions, stone bacterial burden, and obstructive uropathy.

Conclusion: AS have been used in a plethora of laboratory experimental studies. Independent of their similarity to real urinary tract stones, they present a tremendous potential for testing and training for endourological interventions.

Keywords: Artificial stones, kidney calculi, laser, percutaneous nephrolithotomy, shock wave lithotripsy, training, ureteroscopy

Address for correspondence: Dr. Abdulrahman Al-Aown, Department of Urology, Armed Forces Hospital Southern Region, Khamis Mushait, Saudi Arabia.
E-mail: aown22@hotmail.com

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INTRODUCTION

The physical properties of real urinary tract stones can be simulated by the development of artificial stones (AS). Common materials used for the creation of AS initially were Z-brick and plaster of Paris™.[1,2] The gypsum-based materials are extensively used for the development of AS. These phantoms are BegoStone and Ultracal-30.[3,4] BegoStone phantoms present acoustic and mechanical similarities to hard kidney stones, such as calcium oxalate monohydrate (COM) and brushite. Ultracal-30 phantoms are more similar to soft kidney stones composed of uric acid or magnesium ammonium phosphate hydrogen (MAPH). Many other materials and combination of them have been used as model stones, depending on the physical properties that needed to be studied.

Over the years, many experimental procedures have been set up to find out the most appropriate techniques and settings for the safety of the patient and the surgical efficiency. The research on the optimum conditions during lithotripsy and testing newly introduced instruments are fields that AS have been really valuable. Another important aspect of the existence and use of AS is the potential of training younger surgeons to familiarize with innovative surgical techniques and the challenging already existent ones. Furthermore, the development of AS has been valuable in terms of basic science investigation in testing lasers and endourological instruments. The objective of this review is not only to demonstrate the plethora of materials used for the creation of AS but also to present their extensive use in experimental and laboratory studies.

MATERIALS AND METHODS

Evidence acquisition

Search strategy, eligibility criteria, and endpoints

A systematic search of the literature was conducted in December 2021. The study complied with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[5] The aim of this study is to investigate the materials used for the creation of AS, the use of these as a tool for laboratory research, and the possibility of using them in training for endoscopic urological surgeries.

Data extraction

The studies were screened and data were collected by two reviewers independently (AP and KP) based on the inclusion criteria, and relevant data on study characteristics, and outcomes were extracted using a standardized pro forma [Table 1]. The database search included PubMed, Scopus, Cochrane, and Embase and was last checked at December 03, 21. The inclusion criteria in all studies in this review were the existence of AS and their use for any *in vitro*, *in vivo*, *ex vivo* laboratory and training studies. Any discrepancies among the investigators were solved by the senior investigator (PK).

Evidence synthesis

Selection of studies

After the screening of 346 publications, 21 studies were considered eligible to be included in the review. Nine studies looked into experiments regarding the use of holmium: yttrium–aluminum–garnet (Ho:YAG) laser use, six referred to extracorporeal shock wave lithotripsy, three described experimental setups about percutaneous nephrolithotomy (PCNL), one looked into imaging perioperatively for endourological interventions, one investigated stone bacterial burden, and one looked into obstructive uropathy [Table 2]. Figure 1 shows the flowchart of the study.

RESULTS/DISCUSSION

Holmium: yttrium–aluminum–garnet laser-related studies

Ho:YAG laser is widely used for endoscopic lithotripsy procedures as a safe and effective treatment for urinary tract stones.[6] In this *in vitro* experimental study, the authors investigated a way to enhance the safety of this technique through an automatic feedback control system, which does not allow the laser activation if the fiber is not placed near the stone. The identification of stones or tissue occurs by an autofluorescence detection scheme. The authors collected 35 samples of stones with different compositions, extracted from patients. They also created AS and used porcine renal and ureteral tissue. The comparison of the fluorescence ability of these materials was tested. The artificial stone was created from plaster (Limbs and Things, UK), but no further information was given. The results show that AS do not have the same characteristics as the real ones regarding fluorescence. AS do not fluoresce when excited, while urinary tract stones do. The authors concluded that the signal origin may be the organic matrix of real urinary tract stones and it seems that this kind of artificial stone could not be used for further investigation and development of this research field.[7]

Another *in vitro* experimental study took place to explore the most effective settings for the "pop-corn" technique of Ho:YAG laser during ureteroscopy with different laser settings and fiber sizes. The range of settings used was 0.5–1.5 Joules, 10–20 and 40 Hz, and long and short pulses, using 273 and 365 μm laser fibers. The phantoms were

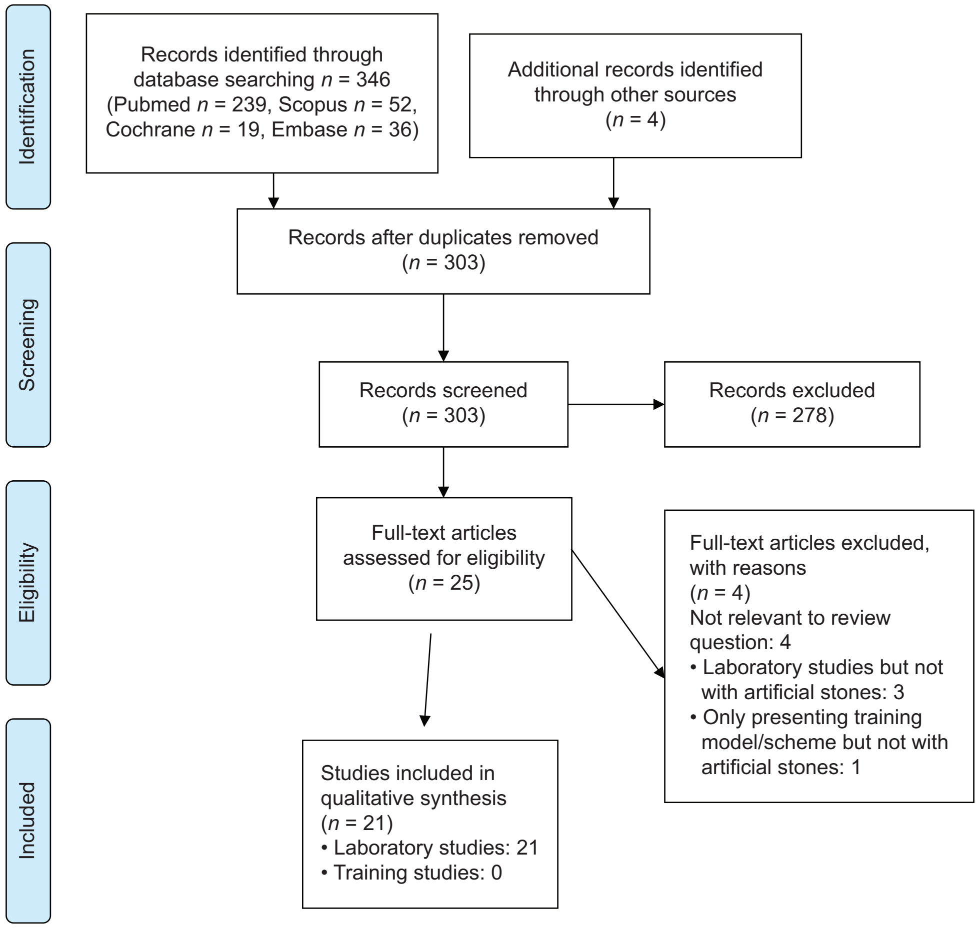

Figure 1: PRISMA flowchart. PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

made with BegoStone with a powder-to-water ratio of 15:3. The mixture was left to dry for 12 h and then it was cut for the creation of 4–5 mm AS. The stones were placed in a Vacutainer. The ureteroscope with the fiber in its working channel was inserted in the Vacutainer via a ureteral access sheath (UAS). After 144 tests, the research team found that the most effective combination of settings for "pop-corn" technique can be achieved with longer pulse, higher energy, high frequencies (>10 Hz), and smaller laser fiber size.[8]

Controlling the settings of a Ho:YAG laser device during ureteroscopy can help the surgeon optimize the operational results. The effect of pulse duration on the laser fiber and on the stone retropulsion and fragmentation was investigated. An *in vitro* experiment was set up to evaluate these parameters. The Ho:YAG-laser Swiss LaserClast® (EMS Electro Medical Systems S. A., Nyon, Switzerland) was used, while AS were created with BegoStone with a powder-to-water ratio of 15:4 and sizes of 7 mm × 7 mm × 7 mm. Ablation and retropulsion were tested in an aquarium experimental setup. For the ablation testing, the fiber was moving with a standard speed adjusted to the repetition rate along the BEGO stone surface in one direction, creating craters on the stone. High-resolution optical coherence tomography (OCT) (TELESTO™ OCT Imaging System, Thorlabs GmbH, Dachau/Munich, Germany) was used for the optical analysis of the craters. Retropulsion was tested by the pendulum method and the first deviation was measured. This *in vitro* research revealed that longer pulse was related to less retropulsion and laser fiber burn back, which may lead to reduction of the operational time. There was no significant difference in fragmentation rates.[9]

The same scientific question was the aim of the experimental *in vitro* study of Bader *et al*. The effect of short and long pulses on stone fragmentation using the Ho:YAG-laser Swiss LaserClast® (EMS Electro Medical Systems S. A., Nyon, Switzerland) was tested. The authors created AS with BegoStone with a powder-to-water ratio of 15:4. The shape of the stones was cubical and the sizes were 7 mm × 7 mm × 7 mm. The laser settings used were 0.5, 1, 2 J and 20, 10, 5 Hz. The researchers tested two different experimental configurations. For the first setup, a practitioner was controlling the fiber and the stone was placed in a glass formation with 2 lattices for

Table 1: Protocol presentation based on PICO

Question: In which laboratory or training schemes are artificial stones used?	
PICO strategy	P Laboratory and basic science investigations *In vivo, ex vivo, in vitro* experiments Technical skills training I Artificial stones: Material and scientific purpose C/O - Evaluation and reporting of results related to Main scientific topic investigated Material used
Search options	Databases to search: Pubmed, Scopus, Cochrane Manual search is acceptable. Articles in peer-reviewed journals and abstracts from major congresses (EAU, WCE, AUA, SIU) Languages: English
Eligibility criteria	Any *in vivo, ex vivo*, and *in vitro* study evaluating artificial stone and the use of artificial stones for laboratory or training study
Search keywords	Artificial, stone, urinary tract, training, laser, PCNL, SWL

PCNL: Percutaneous nephrolithotomy, SWL: Shock wave lithotripsy, EAU: European association of urology, WCE: World congress of endourology , AUA: American urological association, SIU: Société internationale d'Urologie, PICO: P: Patient, problem or population I: Intervention C: Comparison, control or comparator O: Outcome(s)

the fragment collection (handheld fiber fragmentation). For the second setup, a glass with a hole to its bottom for the fiber was used (hands-free fiber fragmentation). The results demonstrated that there was no significant difference between short and long pulses when the other laser settings were similar regarding the stone fragmentation. In conclusion, AS could be used as a tool for comparing different laser settings.[10]

BegoStones were also used in an *in vitro* experimental study for the optimization of the distance between the fiber and the stone regarding the laser efficiency during noncontact lithotripsy. The settings used were single-pulse energies of 2 J and 3 J with short (150 μs) and long (850 μs) pulse durations. The authors conducted lithotripsy when the fiber tip and the artificial stone were in contact and when the distance between them varied from 0.2 mm to 2.0 mm. The researchers created AS mimicking COM stones with a powder-to-water ratio of 15:3. The size of the stones was 24 mm × 20 mm × 18 mm. The fiber and the stones were immersed in natural saline 1 h prior to the lithotripsy. After that, lithotripsy was performed in a tank using a robotic arm for absolute control of the fiber and a 272-μm core silica optical fiber (Rocamed, Monaco) attached to it. A high-speed camera (APX-RS 3000, Photron, San Diego, CA, USA) with magnifying lenses (×3.0, f/4, Edmund Optics, York, UK) was used for measuring and controlling the distance. The laser device used was Ho:YAG laser machine (wavelength of 2100 nm, maximum power output of 30 W, Rocamed, Monaco). An optical microscope (Axio Imager. M2 m, Zeiss, Germany) was used for the analysis of the craters' dimensions. The authors found that ablation rates might be better in noncontact mode using long pulses.[11]

Different laser systems could have different outcomes when it comes to stone fragmentation. The role of different frequency and energy settings on fragmentation with two different laser systems Lumenis Pulse 120H (Lumenis Inc., San Jose, CA) and Rhapsody H-30 (Cook Medical, Bloomington, IN) was evaluated. The authors used BegoStone to create AS with a powder-to-water ratio of 15:3 and sizes of 8 mm. The stones were placed in 0.9% normal saline for 30 min prior to lithotripsy. Afterward, they were placed in a PVC tube filled with natural saline. The ureteroscope with the laser fiber in its working channel was inserted through a UAS. Lithotripsy with different combinations of settings was conducted. The fragments of the stones were collected and weighed. The results of this study showed that the two devices had a similar treatment time. The authors proposed that the fragmentation technique would be more efficient with energy > 1 J and frequency of 10–25 Hz. The H-30 demonstrated slightly better performance regarding retropulsion. AS seem to be a great material for the comparison of these devices and the possible optimization of the settings for endoscopic procedures.[12]

The comparison between high- and low-frequency lithotripsy was investigated by Kronenberg and Traxer with an *in vitro* study. The automated laser fragmentation system was also used in this setting. A fissure was created on the artificial stone. The instruments used were the Lumenis™ VersaPulse® PowerSuite 100 W Lithotripter with a range of settings 0.2–1.2 J pulse energies, 5–40 Hz frequencies, 4–20 W power levels, and 200 or 550 μm core laser fiber (Lumenis – SlimLine™). The material used for the creation of AS was plaster of Paris™, with a powder-to-water ratio of 1.5:1. A calibrated optical microscope (Nikon Labophot 2) was used for the analysis of the fissures and the calculation of their dimensions. The authors concluded that low frequency-high pulse energy offers better fragmentation performance, when used at the same power level.[13]

Management of available ancillary tools could also play an important role for the efficiency during ureteroscopy. Laser fiber tips can be stripped or cleaved, as gradual degradation of the fiber tip occurs during surgery. The effect of fiber management on laser performance was tested by an *in vitro* experiment. The researchers created AS mimicking soft urinary tract stones, like struvite,

Table 2: An overview of the studied included

Studies	Study Aim	Material Used	Phantom Composition	Author, Year of Publication
Holmium: yttrium-aluminum-garnet laser related studies	The possible fluorescence detection of the stone during endoscopic surgery for safety enhancement.	Plaster (Limbs & Things, UK)	N/A	Lange *et al*., 2015[7]
	Evaluation of the "pop-corn" technique with a wide range of holmium laser settings and fiber sizes in a systematic in-vitro assessment.	Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:3	Emiliani *et al*., 2017[8]
	The effect of the pulse duration on the laser fiber and on the stone retropulsion and fragmentation.	Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:4	Sroka *et al*., 2015[9]
	The effect of the pulse duration on the laser fiber and on the stone retropulsion and fragmentation.	Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:4	Bader *et al*., 2015[10]
	The optimazation of the distance between the fiber and the stone regarding the efficiency during non-contact lithotripsy.	Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:3	De Coninck *et al*., 2019[11]
	Evaluation of the role of different frequency and energy settings on fragmentation with two different laser systems.	Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:3	Bell *et al*.,2017[12]
	Assessment of the fragmentation efficiency of laser lithotripsy – comparison of high- with low-frequency lithotripsy	Plaster of Paris™	Powder to water ratio 1.5:1	Kronenberg *et al*., 2014[13]
	The effect of stripping and cleaving the laser fiber tip with specialized tools on lithotripsy performance	Plaster of Paris™	Powder to water ratio 1.5:1	Kronenberg *et al*., 2015[14]
		Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:3	
	1. Identification of the dominant mechanism of Ho: YAG lithotripsy with or without pulse modulation. 2. Investigation of the effect of pulse modulation on stone ablation per joule of emitted radiant energy. 3. Investigation of the suitability of Begostone.	Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:3	King *et al*.,2021[15]
Extracorpeal Lithotripsy related studies	In vitro investigation of the characteristics of stone comminution by burst wave lithotripsy.	Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:3	Maxwell *et al*.,2015[17]
	Evaluation of the suitability of a new extracorporeal electrohydraulic shock wave device (sparker array).	Ultracal-30 (U.S. Gypsum, Chicago, IL)	N/A	Connors *et al*., 2018[18]
	Comparison of three different lithotripters.	Ultracal-30 (U.S. Gypsum, Chicago, IL)	N/A	Faragher *et al*., 2016[19]
	Investigation of the mechanism of fragmentation by drawing attention to basic physical laws of inertia and momentum transfer.	Begostone (BEGO USA, Lincoln, Rhode Island)	N/A	Wess *et al*., 2020[20]
		Plaster of Paris™	N/A	
	Investigation of the effect of bones on stone fragmentation during SWL.	Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:3	Olvera-Posada *et al*., 2016[21]
	The effect of different settings of a piezoelectric lithotripter on stone fragmentation.	Spheres of activated Aluminum (BASF SE, Ludwigshafen am Rhein, Deutschland)	Al2O3 92.5%, SiO2 0.02%, Fe2O3 0.3%, Na2O 0.3%	Veser *et al*., 2020[22]
Percutaneous Nephrolithotimy related studies	Comparison of the fragmentation capacity, clearance time and drilling speed of four different lithotripters.	Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:3	Bader *et al*., 2021[24]
	Comparison of the stone clearence time between three lithotripters, one ultrasonic and two single-probe dual-energy lithotripters.	Begostone (BEGO USA, Lincoln, Rhode Island)	Powder to water ratio 15:3 Powder to water ratio 15:6	Lattarulo *et al*., 2021[25]
	Investigation of the passive stone clearance by hydrodynamic effects under continuous irrigation in different PCNL systems.	Standardized artificial polygonal stone material (Chaton 1028, PP13, Jet 280; Swarovski)	N/A	Mager *et al*., 2016[26]
Urinary tract infections related study	Investigation of the reduction of the stone bacterial burden with the use of photothermal polymer nanoparticles.	Plaster of Paris™ Portland cement Velmix (calcium sulfate powder)	17.1g 15ml water 0.9g 2g	Klein *et al*., 2021[28]
3D CT imaging related study	Reduction of the radiation exposure of endourological patients with the Uro Dyna-CT and optimization the cross-sectional image quality.	Plaster of Paris™	N/A	Rassweiler *et al*., 2014[29]
Obstructive uropathy related study	Investigation of the effects of obstructive uropathy.	Orthoprint-elastic stomatological alginate material (Zhermac)	N/A	Sosnin *et al*., 2013[30]

using plaster of Paris™ (1.5:1 powder-to-water ratio), and harder stones mimicking COM, using BegoStone, with a 15:3 powder-to-water ratio. The size of the stones was 30 mm × 20 mm × 10 mm. Following that, they performed laser lithotripsy using the MH 01-ROCA FTS 30 laser lithotripter (Rocamed, Principality of Monaco) and 272 mm core laser fibers (No. MF272STs, Rocamed, Principality of Monaco) with high frequency-low pulse energy (20 Hz and 0.5 J) and low frequency-high pulse energy (5 Hz and 2.0 J) settings for 30 s. An automated laser fragmentation system was created, offering a stable position of the laser fiber while an artificial stone moved with a stable speed under the fiber. The comparison demonstrated that coated fibers were significantly better regarding the ablation compared to the stripped fibers. In addition, low frequency-high pulse energy offered better lithotripsy performance. The comparison of different settings and alternated techniques of managing the laser fiber on AS could offer valuable information and improvement for endourological procedures.[14]

King *et al*. conducted an experimental study in order to investigate the dominant mechanism of Ho:YAG lithotripsy and the role of pulse modulation on stone ablation. Moreover, they tested the suitability of BegoStone for laser lithotripsy research. Phantom stones were created by BegoStone with a 15:3 powder-to-water ratio and 25 mm × 25 mm × 2 mm size. COM, MAPH, and uric acid anhydrous (Louis Herring, Orlando, FL) stones were also used. Three different stone conditions were tested: dry stones in air, hydrated stones in air, and hydrated stones in water. Dry stones were left for over than 7 days and hydrated stones were immersed in water for over 3 days. The experimental setup was a water tank (filled or empty) with the stone on the bottom, and a stepping motor rotating the fiber (MOSES 200 D/F/L; Lumenis) from the stone to a photodetector. The distance between the laser fiber tip and the stone was 1 mm. The Ho:YAG laser (MOSES Pulse 120H; Lumenis, Yokneam, Israel) settings used were Moses distance (MD) 1 J single pulse, non-Moses short pulse (NM) duration in a single 1 J pulse, and non-Moses short pulse duration consisting of two 0.5 J pulses (NM2 × 0.5 J). The authors measured and compared the temporal profile for each setting, the transmission through 1 mm water, and cavitation bubble collapse pressures. The craters' dimensions and characteristics were analyzed by an OCT system. The authors concluded that the dominant mechanism of Ho:YAG lithotripsy is photothermal and sometimes a photoacoustic element also contributes to fragmentation, based on the stone composition. It seems that ablation volume per joule of emitted radiant energy is increased by pulse modulation, nevertheless it might be composition related. The unique response of BegoStone phantoms to radiation in comparison to human stones suggests that their optical properties should be further examined, as they do not seem suitable for this kind of study.[15]

Extracorpeal lithotripsy-related studies

Shock wave lithotripsy (SWL) has been used since the 1980s for the treatment of urolithiasis, being one of the most reliable nonsurgical and the only extracorporeal therapeutic options.[16] The use of short ultrasound bursts instead of shock waves was investigated in an experimental *in vitro* study. Real and AS were used. The material used for the creation of the stones was BegoStone plaster powder, with a proportion of powder to water of 15:3 by weight, mimicking COM stones. The transducer was placed into a water tank. An adhesive factor was used to fix the stone to transparent polyester membrane attached over a polyvinyl chloride plastic hoop. The progress of the lithotripsy was monitored by a digital camera as different combinations of acoustic exposure were tested. This kind of stone seems ideal for testing the effect of ultrasound, and the authors found that burst wave lithotripsy could be a therapeutic option for the treatment of renal calculi.[17]

Another team tried the creation of a new lithotripter with the use of small electrohydraulic ellipsoidal sparker units. They investigated if an array of these sparker units (sparker array [SPA]) is suitable and safe for lithotripsy. The *in vitro* part of this experimental study tested the possibility of stone fragmentation by the SPA. The stones used were created with Ultracal-30. No further information about the stone creation was given. The *in vivo* part of this experiment tested the safety of the SPA. The AS were inserted into alive anesthetized pigs and then they incurred fragmentation. After that, the kidneys were checked for hemorrhagic lesions with only one out of seven specimens appearing hemorrhagic. The authors proved the effectiveness and safety of this experimental lithotripter.[18]

Although SWL is an effective method of treatment for urolithiasis, there can be variations when using different lithotripters. This hypothesis was the reason for comparison of three different lithotripters: Sonolith i-sys (EDAP TMS, Vaulx-en-Velin, France), Modulith SLX F2 (Storz Medical AG, Tägerwilen, Switzerland), and Piezolith 3000 (Richard Wolf GmbH, Knittlingen, Germany). For the comparison of these devices, the researchers created AS with Ultracal-30. The experiment included fragmentation with 250, 500, and 1000 shocks at the nominal focus. Unfortunately, no further information about the stone creation was given by the authors. The results revealed the inferiority of Sonolith i-sys, compared to the other two devices. These homogenous AS seem to be ideal for comparing the performance of lithotripters.[19]

The law of physics behind SWL and stone fragmentation during the procedure is not fully explained and analyzed. An *in vitro* experimental study aimed to shed light into some basic scientific questions about the movement of the stones during SWL was conducted. The researchers used a bifilar stone suspension to observe the horizontal movements of the stone and its return to the initial position and orientation for repeated exposure of separate identical shocks. The materials used were BegoStone plaster powder for the creation of 3, 7 g spheres, and plaster of Paris™ for the creation of 1 g cubes. No further information about the stone creation was given by the authors. This research suggested that better outcomes could be demonstrated when using a lower focus size, but further investigation should be conducted.[20]

Another interesting *in vitro* study regarding the effect of bones on stone fragmentation during SWL was conducted by Olvera-Posada *et al*. The authors created two ordnance gelatin models mimicking soft tissues and added a porcine spine to the second one, mimicking bone structures. They used BegoStone plaster powder AS (15:3 powder-to-water ratio). The AS were fragmented by Modulith SLX F2 Lithotripter (Storz Medical AG, Tägerwilen, Switzerland) in both models. The fragmentation rate of the second *in vitro* model with the bone structure was significantly reduced. The authors proved by this comparison that bone structures reduced the fragmentation rate of AS.[21]

As for the different settings of a piezoelectric lithotripter (Wolf PiezoLith 3000 Richard Wolf GmBH, Knittlingen, Germany) during SWL, another *in vitro* study was conducted. The authors used model stones consisting of spheres of activated aluminum with composition of $Al2O3$ 92.5%, $SiO2$ 0.02%, $Fe2O3$ 0.3%, and $Na2O$ 0.3% (BASF SE, Ludwigshafen am Rhein, Deutschland). They tested three different focal sizes (2 mm, 4 mm, and 8 mm) and 11 different pulse pressure settings (which refers to the intensity of the pulse). The researchers realized that higher pressure settings and lower focus size result in a more efficient fragmentation. Although the results seem rational, further investigation should be conducted regarding the limitations of the tissues and the possibility of stone migration.[22]

Percutaneous nephrolithotomy-related studies

PCNL remains the gold standard surgery for kidney stones >2 cm and staghorn calculi.[23] Many lithotripsy devices have been tested and used to make this procedure more effective and safer. The authors of the next *in vitro* experimental study tested four different devices: one single-energy device, one dual-energy dual probe (Swiss LithoClast® Master; E. M. S. Electro Medical Systems S. A., Nyon, Switzerland), and two dual-energy single probes (DESP-1, DESP-2) (Swiss LithoClast® Trilogy; E. M. S. Electro Medical Systems S. A., Nyon, Switzerland) (ShockPulse SE®; Olympus Europa SE and Co. KG, Hamburg, Germany). They investigated the fragmentation capacity, clearance time, and drilling speed of these devices using AS. For the creation of these phantoms, they used BegoStone powder with a powder-to-water ratio of 15:3, mimicking COM stones. The stones used were 10 mm × 15 mm and were not immersed in water before the experiments. The lithotripters were tested by four different urologists and the stones were fragmentated under direct view in a submerged hemispherical silicone support. The results revealed the superiority of DESP-1 (Swiss LithoClast® Trilogy; E. M. S. Electro Medical Systems S. A., Nyon, Switzerland) with a clearance time of 26.0 ± 5.0 s and clearly the use of AS of this kind seemed ideal for the comparison of these instruments.[24]

Our experimental team has also conducted an *in vitro* and *in vivo* experimental study in order to compare the stone clearance time between three lithotripters: one ultrasonic and two single-probe dual-energy lithotripters. The devices tested were the LithoClast Master (Swiss LithoClast® Master; E. M. S. Electro Medical Systems S. A., Nyon, Switzerland), the LithoClast Trilogy (Swiss LithoClast® Trilogy; E. M. S. Electro Medical Systems S. A., Nyon, Switzerland), and the ShockPulse-SE (ShockPulse SE®; Olympus Europa SE and Co. KG, Hamburg, Germany). For both *in vitro* and *in vivo* experimental settings, BegoStone was used for the creation of the stones. Two types of stones were created to simulate hard (powder-to-water ratio 15:3) and soft (powder-to-water ratio 15:6) urinary tract stones. The results of our research showed the superiority of the LithoClast Trilogy (Swiss LithoClast® Trilogy; E. M. S. Electro Medical Systems S. A., Nyon, Switzerland) and come to an agreement with the experimental study of Bader *et al*.[24] The different types of AS were ideal for the comparison of lithotripters.[25]

The passive stone clearance by hydrodynamic effects under continuous irrigation in different PCNL systems was investigated with an *in vitro* experiment by Mager *et al*. The experimental team created a watertight model of renal pelvis surrounded by a cylindrical cast. They tested 12 different nephroscopes of two companies (Karl Storz Endoskope and Olympus) with continuous flow and open Rutner sidearm. Standardized artificial polygonal stone material (Chaton 1028, PP13, Jet 280; Swarovski) was placed in the pelvic phantom and then the nephroscopes were inserted through a sheath. The amount of stone that was suctioned was measured. No further information about the stone material was given. The authors found that medium and large continuous-flow PCNL instruments could remove even the clinically insignificant fragments and dust.[26]

Urinary tract infections

The existence of a urinary tract stone could be the reason for the onset and continuation of infection due to obstructive uropathy.[27] The reduction of the stone bacterial burden was investigated by the following experiment. The authors used real and AS. The AS were created by mixing 18 g of gypsum cement (17.1 g of plaster of Paris™ and 0.9 g of Portland cement) with 2 g of Velmix (calcium sulfate powder) and 15 ml of deionized water. Both stones were inoculated with *Escherichia coli* and incubated with photothermal polymer nanoparticles. After the photothermal treatment, the authors found that the bacterial colonies were less or nonexistent for the stones with the nanoparticles. Nevertheless, the temperature rise was significant during this experiment and further studies need to be conducted to investigate if there is a safe way to use it on patients.[28]

Three-dimensional computed tomography imaging

Quality imaging is a must for stone treatment, giving us information about the stone location and size. X-ray imaging is also used perioperatively for URS and PCNL surgeries. Rassweiler *et al*. developed examination protocols using Uro Dyna-computed tomography (CT) (Siemens, Erlangen, Germany). This device can provide CT-like images with low-dose radiation and can also be used perioperatively. The authors used a Rando–Alderson phantom (The RANDO Phantom, Alderson Research Laboratories Inc., Stamford, CT, USA), which is a male model with thermoluminescence dosimeters, and placed AS in its kidney area. The stones were created with plaster of Paris™, but no further information about their composition was given. The researchers developed soft tissue and hard contrast three-dimensional CT protocols with low-dose radiation that could be used perioperatively.[29]

Obstructive uropathy

Obstructive uropathy is a common urological emergency that can be caused by urolithiasis. The effects of obstructive uropathy were investigated in this experimental study. The researchers injected Orthoprint (Zhermack, Badia Polesine, Italy), a highly elastic stomatological alginate material into the bladder of mice, through the urethra. This material formed a stone in the bladder, partially blocking the ureteral orifices and the urethra, and caused incomplete obstructive uropathy. The mice were sacrificed on days 14 and 21. Renal inflammation and nephrosclerosis were demonstrated in both groups. In addition, the concentration of total protein and activity of γ-glutamylaminotransferase of the urine was increased. Unfortunately, no further information about the stone material was given, although it was used successfully for the cause of obstructive uropathy to mice.[30]

CONCLUSION

AS are created to simulate urinary tract stones and have been used in numerous experimental studies. They are used not only for testing new instruments or techniques but also for investigating the safest and most efficient combination of settings for preexistent surgical modalities. In addition, the comparison between different instruments or techniques would not be so easy and could not be safely tested without using these kind of phantoms. It is clear that a synthetic material may not have the same properties as a real kidney stone; however, it seems that there is much potential in the field of training young urologists for endoscopic surgeries with AS, and hopefully, they will be soon part of advanced training courses too.

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Conflicts of interest

There are no conflicts of interest.

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