University of Thi-Qar Journal of Science (UTsci)
ISSN Onlin:2709-0256, ISSN Print: 1991-8690 Volume (8), No.2,Oct.2021

Studying the Effect of the Energy Settings of the HO-YAG Laser and the Composition of the Stones on the Fragmentation Time *in vitro*

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***Abstract*-Among the many *in vitro* lithotripsy devices, a holmium-YAG laser lithotripter has been developed to treat urinary tract stones . This research aims to show the effect of the coefficients of the Ho-YAG laser at wavelength 2100 nm on the *in vitro* fragmentation time and stone composition by checking the stone formation and stabilization of the energy of the pulsed holmium laser while calculating the time required to break the stone . From March 2020 to October 2020, 50 ureteral stone samples were collected from 50 patients (as a result of lithotripsy surgery <10 mm) between the ages of 10-85 years . The patient was treated in the Urology department of Al-Hussein Teaching Hospital by using a Ho-YAG laser radiation wavelength of 2.12 µw, the reaction absorption coefficient 30 cm^{-1}, with a maximum output power of 20 watts, for a laser pulse width of 350 microseconds in an optical fiber with a diameter of 272-550 microns with a power of 0.8 - 1.2 J at 6-8 Hz. The samples obtained are selected groups of stones recovered after lithotripsy. This study showed that the average size of the stones less than 10 mm was 9.5 ± 0.7 mm for the first group of stones of the same composition (calcium oxalate monohydrate), and the mean age of the patients was 31 ± 2.82 years and the time of fragmentation (70 ± 1.41) sec, with a pulse energy of 0.8 J with a repetition rate of 6 Hz. The mean age of the patients was 24.5 ± 12.02 years for a mean stone size of 10 ± 1.41 mm with a lithotripsy time (61.5 ± 2.12) s, with a pulse energy of 1.2 J and a repetition rate of 8 Hz. The second group of stones (calcium oxalate dihydrate), the mean age of the patients was 29.5 ± 16.26 years for the mean stone size (7 ± 1.41) mm, and the time to disintegration (57 ± 2.12) seconds, with a pulse energy of 0.8 J and repetition rate of 6 Hz. The mean age of patients was (25 ± 4.24) years for mean stone size (8.5 ± 0.7) mm. Fragmentation time (51 ± 1.41) s with a pulse energy of 1.2 J at a repetition rate of 8 Hz . Group III (uric acid) stones had a mean age of patients (18 ± 2.82) years with a mean stone size of (8.5 ± 0.7) mm and a dissolving time (30 ± 1.41) seconds, with a pulse energy of 0.8 J with a repetition rate of 6 Hz and patients' mean age (32 ± 4.24) years for mean stone size (8 ± 2.82) mm and disintegration time (20.5 ± 2.12) s, with a pulse energy of 1.2 J at a repetition rate of 8 Hz . Group IV stone (struvite) patients had a mean age of (16 ± 11.31) years with mean stone size (10.5 ± 4.94 mm), mean disintegration time (15 ± 1.41) s, with a pulse energy of 0.8 J at a repetition rate of 6 Hz and a mean Patients' age (20 ± 10.6) years for mean stone size (9 ± 1.41) mm and fragmentation time (9 ± 1.41) sec, with a pulse energy of 1.2 J at a repetition rate of 8 Hz . The fifth group of stones (cysteine) for the average age of the patients was (37 ± 0) years for the mean stone size (6.5 ± 0.7) mm and disintegration time (89 ± 1.41) seconds, with pulse energy 0.8 J with a repetition rate of 6 Hz and a mean Patients' age (33 ± 0) years had a mean stone size (7 ± 2.82) mm with a fragmentation time (84 ± 1.41) s, with a 1.2 J pulse energy at an 8 Hz repetition rate. Ho-YAG laser lithotripsy is an excellent treatment method related to the time required for lithotripsy with the type of stones and the different laser settings used .**

***Keywords* : Ho-YAG laser, pulse energy, laser lithotripsy, frequency setting .**

I. Introduction

Urinary stones consider are one of the most common agonizing disturbances of the urinary system. Four new technologies progress have the treatment of urinary lithotripsy electrohydraulic lithotripsy, ultrasonic lithotripsy, extracorporeal shock wave lithotripsy, and laser lithotripsy [1] .

If the stone is too large to pass on its own or is caught in a difficult place it will block the flow of urine and causes an ongoing urinary tract infection that damages kidney tissue or causes constant bleeding Methods of interventions management :- Open Surgery (lithotomy) Ureteroscopic Stone Removal Percutaneous Nephro Lithotomy (PNL),Ureteral (double-J) stents [2] .Because of advancements in endoscopic technology and lithotripsy, urinary tract stone treatment has achieved widespread acceptance [3] . Because of the advancement of small equipment and the entry of laser science into medicine, using laser for urolithiasis management is now a viable option [1] ureteroscopic surgery Ho : YAG laser lithotripsy is a preferred method for treating urinary stone disease [4] . Compared to open surgery, the invention of ureteroscopy appliances and other smaller endoscopy instruments resulted in better calculi fragmentation, more effective calculi evacuation, a larger number of free calculi, and lower morbidity rates [5, 7] . This laser is the source of electricity Endoscopes can deliver laser power to both flexible and rigid optical fibers[6]. Due to its high performance and small diameter, availability has become the lithotripsy system of choice [8] .

Optical fibers transmit energy to fragment stones, and their safety profile has previously been demonstrated to be superior to that of other lithotrities, particularly in terms of ureteral perforation risk. [9]. When it comes to technicality and laser settings, stone location is a variable that must be considered. When handling stones in the ureter, retropulsion is more of a problem[10,11]. The structure of kidney stones is responsible for their formation, which contributes to their formation environment. The crystalline structure of stones must be determined to determine the etiology and manage the recurrent stone disease**.**[12] Owing to biological incompatibility, minerals accumulate and agglomerate on the inner surfaces of the kidneys, forming stones that are hard masses like small rocks. [13]. Many researchers have identified seven distinct forms and twenty-one subtypes of kidney stones, including monohydrate and dihydrate calcium oxalates, phosphates, uric acid, urates, protein, and cystine calculi. Urinary stone analysis can be performed in several different ways. Optical crystallography X-ray, diffraction, infrared spectroscopy, X-ray spectroscopy, and thermogravimetry are some of the physical methods used in stone research. These methods necessitate complex equipment, are only semi-quantitative and do not detect minor constituents of mixed calculi [14] .

Causes of Urinary Stones: Low fluid intake leads to low urine volume, which results in high concentrations of stone-forming solutes in the urine. This case is an important environmental player in the development of kidney stones[15]. The four major chemical forms of renal calculi are mentioned below, each of which is linked to more than 20 underlying causes: Calcium stones, struvite (magnesium ammonium phosphate) stones, uric acid stones, cystine stones, and calcium stones: Recent research suggests that in hypercalciuric stone formers, a low-protein, low-salt diet may be preferable to a low-calcium diet for preventing stone recurrences. Struvite (magnesium ammonium phosphate) stones are linked to a chronic urinary tract infection (UTI) caused by gram-negative, urease-positive bacteria that break urea into ammonia, which binds to phosphate and magnesium to form calculus stones made up of uric acid. These are linked to a pH of urine below 5.5, a high purine diet (e.g., organ meats, legumes, fish, meat extracts, gravies), or cancer (i.e., rapid cell turnover). Stones of Cystine appear as a result of an intrinsic metabolic defect that causes cystine, ornithine, lysine, and arginine reabsorption failure in the renal tubules Urine becomes cystine supersaturated, resulting in crystal deposition. [16- 18] .

II. Materials and Methods

Laser Source

Specimens of ureteric calculi used provided by the 63 patients were treated with lithotripsy at Hussein Teaching Hospital's urology clinic. This analysis aimed to see how the wavelength of the Ho-YAG laser irradiation affected the results (2.12 nm). In an optical fiber with a diameter of 230-600 microns and an energy of 0.8-1.2 joules at 6-10 Hz, the width of the laser pulse is 350 microseconds at maximum peak power (1.2-0.5 J).In addition to a camera, monitor, and light source (all from Karl Storz TM) with An semi rigid ureter scope 40 cm length with 12^{o} Lens and 5 Fr (PUSEN TM 9 Fr., with 270 deflections in both sides) with use Irrigation with Normal saline.

Image1. Ho-YAG laser irradiation wavelength at 2100 nm.

Patients

From patients with ureteral stones, 50 patients were selected to be included in this study (Outcome of surgery for lithotripsy ureteral stone below 10 mm by laser) has been 10 – 85 years for male and female collected, for the duration from March 2020 to August 2020.

Holmium laser therapy is indicated for patients with ureteric calculi. It is possible to perform ureteroscopic laser lithotripsy of ureteric calculi. Before laser lithotripsy, patients with high-grade obstruction can require the placement of a ureteral stent. Laser energy was launched into a (230m,356m,600m) diameter optical fiber and applied to the stone's surface in contact mode (2100nm Ho: YAG laser). The laser pulses were 350 microseconds in length. The initial setting was adjusted from 0.8 to 1.2 J at 6 to 10 Hz to fragment most stones. As the stone absorbs laser irradiation, an audible " tic, tic " sound is made, in a fluid environment, determined by using water with calculating the time for crushing calculi. Analysis of stone fragmentation using (2100 nm Ho: YAG laser was evaluated. Different sizes, shapes, and compositions of human urinary stones were used. Urinary stones of known composition with different sizes, shapes were used for this study Stones were then hydrated in water for more than one week. The samples obtained were selection collections of fragments retrieved following lithotripsy.

Stone Sample Preparation

Human urinary stones were soaked in water before being used to guarantee that no traces of urine, blood, or other biological or chemical contaminants remained. After that, the calculi were dried in an oven. Different stones types were submerged in glass tubes containing normal saline with the tip of the laser fiber placed 2 mm from the stone and irradiated with wavelength at 2100 nm light of Ho: YAG laser, as shown in Image 2

Image 2: The samples of stone immersed in normal saline before exposure to Ho-YAG laser.

We were sent to a biochemistry lab for qualitative chemical analysis for various potential chemical compositions in order to determine the chemical compositions of the extracted urinary stones. The stones were ground into a fine powder before being examined using standard chemical techniques. Calcium (Ca), oxalate (OX), phosphate (PO4), urate (UA), magnesium (Mg), carbonate (Co_3), and amino acids (AA) Use infrared spectroscopy within the range (400-4000) cm^{-1} using a (Bruker FTIR - Spectrometer) device and using a potassium bromide tablet at Chemistry Department at College of Science/ University of Thi-Qar.

Image 3: Bruker FTIR-Spectrometer device and using a potassium bromide tablet at University of Thi-Qar/ College of Science/Department of Chemistry.

The absorption of laser irradiation by the stone creates an audible "tic, tic" sound as fragmentation occurs. In a fluid environment, the laser energy must be applied as close as possible to the stone or in the contact mode and then activating the laser. A foot-operated switch will activate and deactivate the release of the laser energy from the lithotriptor. For all exposures, the optimum laser output was 20 W. However, the pulse repetition rate was varied from 6 to 8 Hz resulting in pulse energies ranging from 0.8 to 1.2 J/pulse. After each laser irradiation, the laser parameters and the time of each stone fragmentation were recorded, and the stones fragments were sorted as shown in Image 4.

Image 4: The samples of irradiated stone after exposure to Ho-YAG laser represent different energies.

III. Results and Discussion

The efficiency of the Ho: YAG laser for fragmentation of these stones at different energy settings was studied (*in vitro*). Holmium laser lithotripsy has shown excellent results in the treatment of urinary stones. The effect of stone installation on fragmentation time depends on the pulse energies and frequency settings changes.

The first group of the same composition (calcium oxalate monohydrate) the following is the findings of an FT-IR study of a variety of materials of COM samples as follows: Diagnostic band identified for a pure oxalate of calcium monohydrate absorbance at

1621.16 cm^{-1}an 1318.52 cm^{-1}. Once belonged to C=O and C-O stretching, respectively. The frequency range was set to 780.27cm^{-1}, agreeing with C-H bending the absorption band at a certain angle 3494.92-3065.48 cm^{-1} due to symmetric and asymmetric O-H bending. This occurred as a result of symmetric and asymmetric O-H bending. The band of absorption at 1318.52 $cm^{-1}$was as a result of C-C, C-O extending,882.67 cm^{-1} because of C-C extending [19] as presented in Fig.1

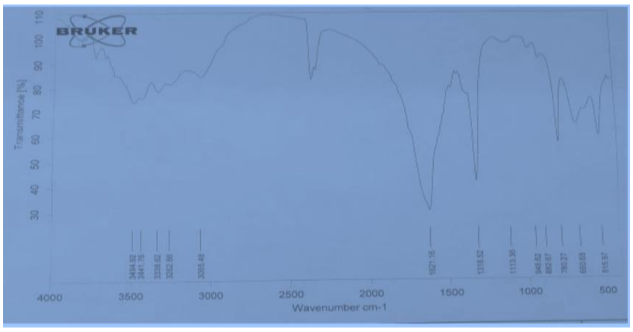

Fig.1 : FTIR spectrum of pure COM .

The average age of the patients was(31±2.82) years for average stone size was (9.5±0.7) mm, mean the breakup time (70±1.41) sec, with pulse energies of 0.8 J with repetition rate was 6 Hz for a power output of 20W as shown in the figure. The average age of the patients was (24.5±12.02) year for average stone size was (10±1.41) mm, mean the breakup time(61.5±2.12) sec, with pulse energies of 1.2 J with repetition rate was 8 Hz for the average power of 4.8 W (6 Hz x 0.8 J/ Pulse) and 9.6 W (8 Hz x 1.2J/Pulse) was delivered through 550 microns fibers as shown in figure 2. A and B. The study shows a significant relationship between the breakup time and stone size, as shown in Table 1 .

PE (J)	PRR (HZ)	P (W)	Operative time (sec)	Stone size (mm)	Age	P-value
0.8	6	4.8	70±1.41	9.5±0.7	31±2.82	0.04 S
1.2	8	9.6	61.5±2.12	10±1.41	24.5±12.02	0.01 S

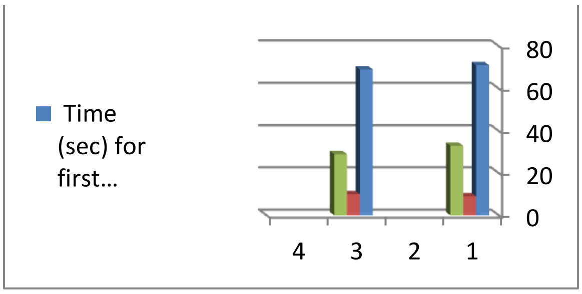

Figure 2. A: The relationship between the breakup time and stone size for oxalate calcium monohydrate with 0.8 *in vitro* .

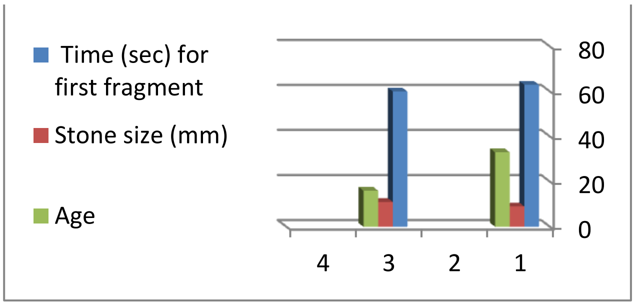

Figure 2. B: The relationship between the breakup time and stone size for oxalate calcium monohydrate with 1.2 *in vitro* .

The second group of the same composition (calcium oxalate dihydrate), the infrared spectrum, is characterized by the appearance of absorption beams at 1638.61 cm^{-1} because of the expansion of the C=O.The absorption beam at 1324.92 cm^{-1} because of expansion of the C-O. The absorption beams at 782.33 cm^{-1} back to curvature C-H and the absorption beams between (3495-3060) cm^{-1} were due to symmetric and asymmetric OH expansion[20], as shown in figure 3.

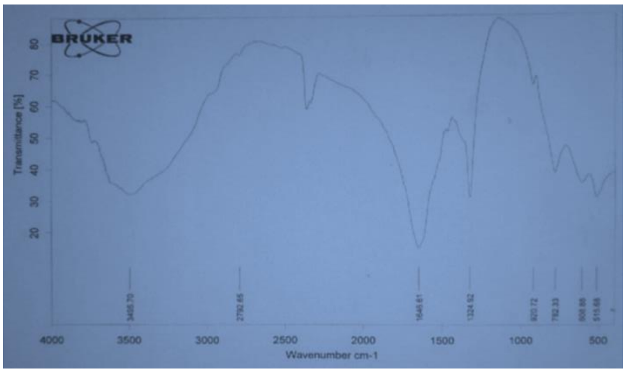

Figure 3: FTIR spectrum of COD.

The average age of the patients was 29.5±16.26 years for average stone size was (7±1.41) mm, mean the breakup time(57±2.12) sec, with pulse energies of 0.8 J with repetition rate was 6 Hz. The average age of the patients was (25±4.24) year for average stone size was (8.5±0.7) mm, mean the breakup time(51±1.41) sec, with pulse energies of 1.2 J with repetition rate was 8 Hz for the average power of 4.8 W (6 Hz x 0.8 J/ Pulse) and 9.6 W (8 Hz x 1.2J/Pulse) was delivered through 550 microns fibers as shown in figure 4 A and B. The study shows a significant relationship between the breakup time and stone size, as shown in Table 2.

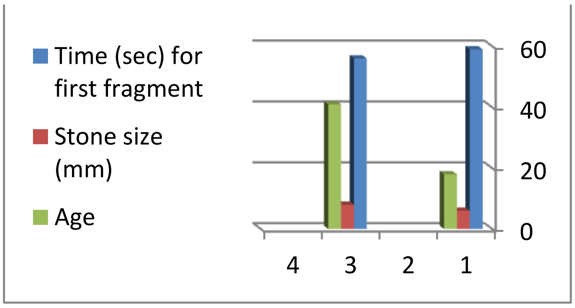

Figure 4. A: The relationship between the breakup time and stone size for oxalate calcium dihydrate with 0.8 *in vitro*.

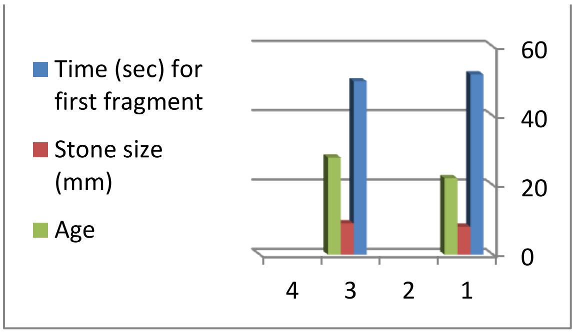

Figure 4. B: The relationship between the breakup time and stone size for oxalate calcium dihydrate with 1.2 *in vitro*.

The third group of 21 stones of the same composition (Struvite Stones) was very easily distinguished in the infrared spectrum in figure 4.2.8 by having a peak at 1033.70 cm^{-1} which shows the PO_4^{-3}. The absorption beam between 2923.59-2856 cm^{-1} because of the expansion of NH at 1688.09 cm^{-1} because of the expansion of group C=O. The absorption beam at 1323.05 cm^{-1} because of the expansion of group C-O, the absorption beam at 837.25 cm^{-1}because of the expansion of C-C, and the absorption beam between (1627-1622) cm^{-1} due to curvature of NH[21] as shown in figure 5 .

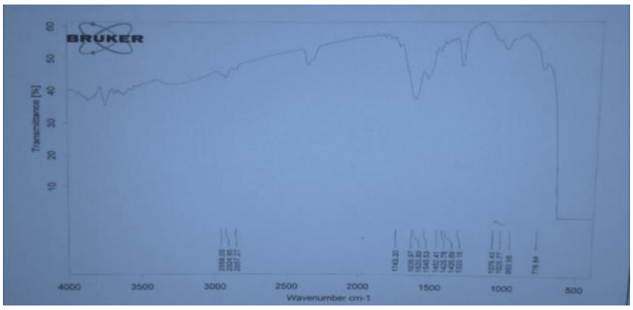

Figure 5: FTIR spectrum of Struvite Stone.

The average age of the patients was 16±11.31 years for average stone size was (10.5±4.94) mm, mean the breakup time (15±1.41) sec, with pulse energies of 0.8 J with repetition rate was 6 Hz as shown in figure 6. A and the average age of the patients was

PE (J)	PRR (HZ)	P (W)	Operative time (sec)	Stone size (mm)	Age	P-value
0.8	6	4.8	57±2.12	7±1.41	29.5±16.26	0.01 S
1.2	8	9.6	51±1.41	8.5±0.7	25±4.24	0.01 S

20±10.6 years for average stone size was (9±1.41) mm, mean the breakup time(9±1.41) sec, with pulse energies of 1.2 J with repetition rate was 8 Hz for the average power of 4.8 W (6 Hz x 0.8 J/ Pulse) and 9.6 W (8 Hz x 1.2J/Pulse) was delivered through 550 microns fibers as shown in figure 6. B. The study shows a significant relationship between the breakup time and stone size, as shown in Table 3.

PE (J)	PRR (HZ)	P (W)	Operative time (sec)	Stone size (mm)	Age	P-value
0.8	6	4.8	15±1.41	10.5±4.94	16±11.31	0.04 S
1.2	8	9.6	9±1.41	9±1.41	20±10.6	0.01 S

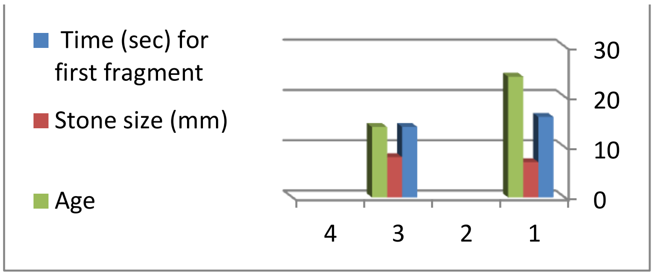

Figure 6. A: The relationship between the breakup time and stone size for struvite with 0.8 J *in vitro*.

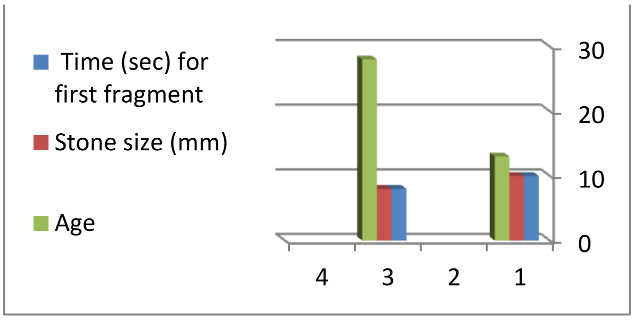

Figure 6. B: The relationship between the breakup time and stone size for struvite with 1.2 J *in vitro* .

The Fourth group of the same composition (Uric acid Stones,) the infrared spectrum was characterized by the emergence of absorption beams between 2850-2924 cm^{-1} because of the expansion of NH, an absorption beam between 1616-160) cm^{-1} because of the expansion of group C=O. The absorption beam between 1302-1314 cm^{-1} from the expansion of group C-O . The beam of the absorption between 1585-1540 cm^{-1} due to the expansion group of the C-N[22], as shown in figure 7.

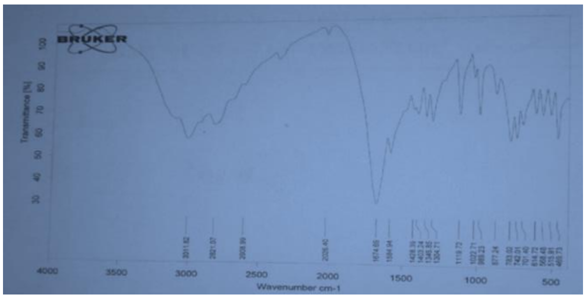

Figure 7: FTIR spectrum of pure Uric acid.

The average age of the patients was 18±2.82 years

PE (J)	PRR (HZ)	P (W)	Operative time (sec)	Stone size (mm)	Age	P-value
0.8	6	4.8	30±1.41	8.5±0.7	18±2.82	0.02 S
1.2	8	9.6	20.5±2.12	8±2.82	32±4.24	0.04S

for average stone size was (8.5±0.7) mm, mean the breakup time(30±1.41) sec, with pulse energies of 0.8 J with repetition rate was 6 Hz as shown in figure 8. A and the average age of the patients was (32±4.24) year for average stone size was (8±2.82) mm, mean the breakup time(20.5±2.12) sec, with pulse energies of 1.2 J with repetition rate was 8 Hz for the average power of 4.8 W (6 Hz x 0.8 J/ Pulse) and 9.6 W (8 Hz x 1.2J/Pulse) was delivered through 550 microns fibers as shown in figure 8. B . shows a significant relationship between the breakup time and stone size, as shown in Table (4).

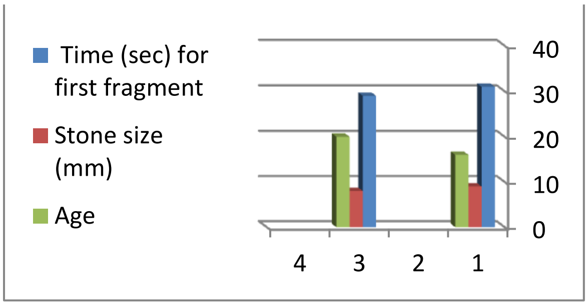

Figure 8. A: The relationship between the breakup time and stone size for Uric acid with 0.8 J *in vitro*.

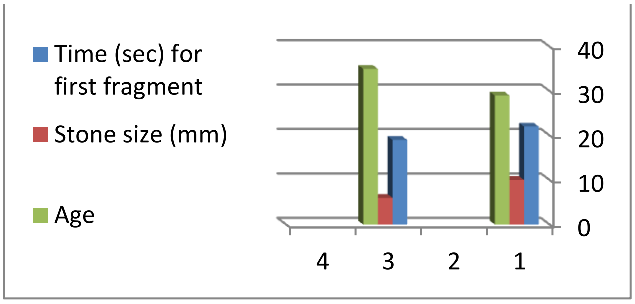

Figure 8. B: The relationship between the breakup time and stone size for Uric acid with 1.2 J *in vitro*.

The fifth group of the same composition (Cystine Stones), the infrared spectrum, is characterized by the emergence of absorption beams between (1619-1600) cm^{-1} due to group C=O expansion. The absorption beam at 2025 cm^{-1} due to the expansion of group S-H and at 878.19 cm^{-1} due to the expansion of group C-C. The absorption beam at 1588.41 cm^{-1} because of the expansion of group C-N. Besides, the absorption beam at 878.68 cm^{-1} is due to the curvature of C-N. The absorption beam between 2853.95-2925.06cm^{-1} due to the expansion of NH[23], as shown in figure 9 .

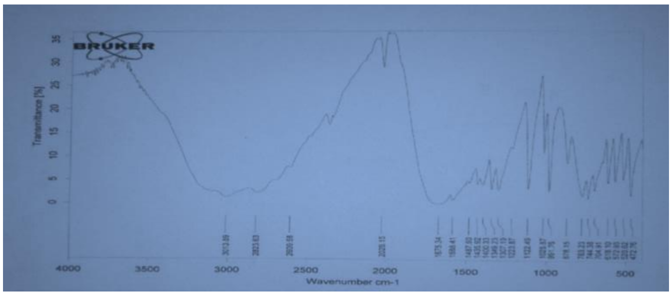

Figure 9: FTIR spectrum of Cystine Stone.

The average age of the patients was (37±0) year for average stone size was (6.5±0.7) mm, mean the breakup time (89±1.41) sec, with pulse energies of 0.8 J with repetition rate was 6 Hz as shown in figure 10. A and the average age of the patients was (33±0) year for average stone size was (7±2.82) mm, mean the breakup time(84±1.41) sec, with pulse energies of 1.2 J with repetition rate was 8 Hz for the average power of 4.8 W (6 Hz x 0.8 J/ Pulse) and 9.6 W (8 Hz x 1.2J/Pulse) was delivered through 550 microns fibers as shown in figure 10.B. Shows a significant relationship between the breakup time and stone size as shown in Table (5)

PE (J)	PRR (HZ)	P (W)	Operative time (sec)	Stone size (mm)	Age	P-value
0.8	6	4.8	89±1.41	6.5±0.7	37±0	0.04 S
1.2	8	9.6	84±1.41	7±2.82	33±0	0.01 S

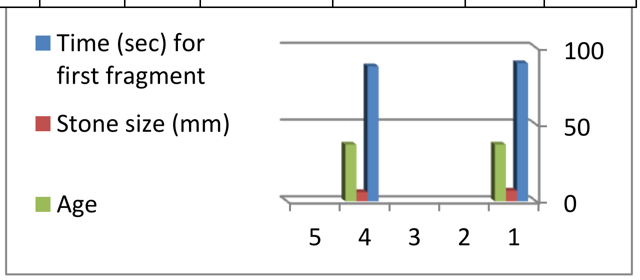

Figure 10.A: The relationship between the breakup time and stone size for Cystine with 0.8 J *in vitro* .

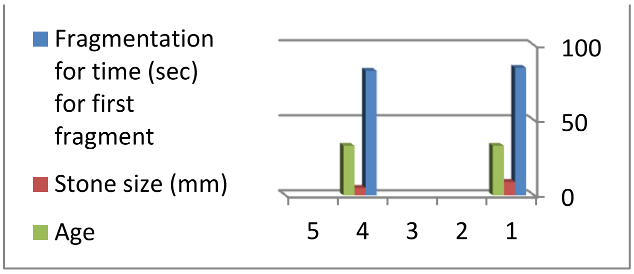

Figure 10. B: The study shows a significant relationship between the breakup time and stone size for cystine with 1.2 J *in vitro*.

Conclusion This study aimed to investigate fragmentation efficiency on the stone. The difference in the laser settings (pulse energy, pulse duration, and repetition rate) and stone installation resulted in a change in the crushing time required for fragmentation *in vitro*.

Statistical Analysis

Data entry and processing were done with the statistical kit for Social Version 23 (SPSS23). The mean and standard deviation for continuous variables are Shown, while the number for discrete variables is shown (percent). The T-test for independence was used to determine the significance of an association for a continuous variable. The Chi-square test was used to determine the significance of an association for a discrete variable with a p-value of less than 0.05 were thought necessary.

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