Chapter 2

Invitro study on the efficiency of laser lithotripsy treatment for natural urinary stones

2.1 INTRODUCTION

Urolithiasis is a very painful ailment which has been prevailing from the middle ages to 21st century (Mitra et al., 1998) The treatment for Urolithiasis or kidney stones is of high necessity; since the disease is high painful and the reluctance in treating at right time may led to renal failure and thereby to morbidity (Greenwood et al., 1982). The treatment of urolithiasis has been tremendously upgrading day by day, starting from traditional open surgical method to the latest laser lithotripsy treatment. The surgical removal of kidney stones has been started by Sushruta in 8th century BC (Friedman, 2008). This treatment is highly painful and can even cause the death of the patient, hence thereby in 1980 the Dornier systems worked in hand in hand with University hospital, Munich to develop a non invasive treatment technique to fragment the stones called shock wave lithotripsy (SWL). The shock wave lithotripsy uses shock waves to fragment the stones, but this treatment proved to have less efficiency if the patient has a stone size above 2cm (Leveillee et al., 2003). This disadvantage lead to the development of latest technique called laser lithotripsy, in which laser beams are used for fragmenting the stones. This technique is invasive and said to have better efficiency than SWL technique (Cotton et al.,1990).

Laser lithotripsy can be used to fragment bigger stones which overcomes the disadvantage of SWL technique though the treatment has its own negative effects which will be studied clinically in this chapter. This chapter deals with the measurement of laser parameters like stone ablation rate (SAR) and fibre tip degradation rate (FTDR) on surgically removed kidney stones. The analysis will give a detail through the negative effects of laser lithotripsy, which can be given better care or can develop the next generation treatment technique for urolithiasis. The most commonly used laser lithotripter is made up of Ho:YAG laser since so far this laser has given its maximum efficiency for lithotripsy treatment.
2.2 EXPERIMENTAL PROCEDURE

2.2.1 COLLECTION OF SURGICALLY REMOVED STONES

The urinary stones are collected directly from the patients underwent the surgery in medical college (Govt Medical College, Trivandrum, Kerala). A total of 6 samples were used for further studies which were named as sample 1 to sample 6 respectively as shown in Fig 2.1.
Fig 2.1: The surgically collected stones and labelled as (a) Sample 1 (b) Sample 2 (c) Sample 3 (d) Sample 4 (e) Sample 5 (f) Sample 6 respectively.
2.2.2 PRESERVATION OF STONES

The collected stone samples are washed with buffer saline solution and dried. After drying the stone is dipped in formaldehyde solution to avoid decaying. The preservation of the stone is necessary, since some stone can react with the atmosphere and can smash by itself or can produce a pungent smell as time passes.

2.2.3 X RAY DIFFRACTION (XRD) CHARACTERIZATION

All the samples collected are unknown about its chemical composition. The chemical composition of each sample is analysed by giving for XRD characterization. A small portion of the sample is taken and powdered properly and is subjected to characterization. The XRD is done using the instrument PANalytical Model X’pert PRO X-ray diffractometer with Cu-Kα radiation (of wave length 1.54060 Å).

2.2.4 FOURIER TRANSFORM INFRA RED (FTIR) CHARACTERIZATION

The functional groups of the stones are confirmed using FTIR. This has been done using the instrument Thermo Nicolet model AVATAR 330 Spectrometer.

2.2.5 LASER LITHOTRIPSY PARAMETER STUDY

After analysing the stone composition, each stone has been subjected to lithotripsy studies. These studies have been carried out with the help of a Ho: YAG laser lithotripter with an optical fibre of dimension of 230 µm x 3 m with flexible ureteroscope. The experiment has been conducted for three different powers such as 10 W, 12 W and 17 W for a fixed time of 60 seconds. The lithotripsy parameters such as stone ablation rate (SAR) and fibre degradation rate have been calculated for each sample.

2.3 RESULTS AND DISCUSSIONS

2.3.1 XRD CHARACTERIZATION AND ANALYSIS OF SAMPLES

The surgically operated stones have unknown chemical composition. The details of stone type is necessary to compare the lithotripsy results, hence all the samples has been given for XRD characterization.
The XRD pattern of each sample has been compared with the already reported XRD patterns to match the peaks and determine the compound present in the sample. The XRD pattern of sample 1 and its matched report has been showed in Fig 2.2 (a) as well as Fig 2.2 (a1). The XRD pattern of the sample has been matched with the JCPDS-99-100-0775 which proves that the first sample composition contains calcium oxalate monohydrate.

The XRD pattern of the sample 2 and its match report has been given in the Fig 2.2 (b) and Fig 2.2 (b1). The pattern has been matched with the JCPS-00-044-0763 which shows that the majority of the peaks are for calcium phosphate hydrate.

The sample 3 gives quite a distorted XRD pattern due to the high level of impurities present in the natural sample as shown in Fig 2.2 (c). This pattern has been matched with the JCPDS-00-049-0496 as given in Fig 2.2 (c1) and the peaks prove that the composition of sample 3 contains calcium phosphate (pure).

The sample 4 XRD has been matched with JCPDS-99-202-3730 and both the patterns is shown in Fig 2.2 (d) and (d1) respectively. The peaks have proved that the stone contains a guanidium urate monohydrate which is a very rare composition of urinary stones. These stones mainly occur if the patients are prone to uricemia or genetic disorders mainly an imbalance of purine metabolism.

The XRD and match report of sample 5 has been shown in Fig 2.2 (e) and (e1) respectively. The patterns had been well matched with the JCPDS-99-100-0775 which proved the stone contains calcium oxalate monohydrate (pure) where these are the most common type of stones present in human body.

The sample 6 XRD pattern and match report has been given in Fig 2.2 (f) and Fig 2.2 (f1). The majority peaks has been matched with the JCPDS- 00-015-0177 which proves that the composition contains the traces of calcium phosphate.

The entire XRD analysis give the details of the major constituent of each samples, though the natural stones probably won’t be containing one composition alone, hence the FTIR characterization is done to find the traces of other elements present in each samples.
Fig 2.2: The XRD patterns and match reports of (a, a1) sample 1 (b,b1) sample 2 (c,c1) sample 3, (d,d1) sample 4, (e,e1) sample 5, (f,f1) sample 6 respectively.
2.3.2 FTIR CHARACTERIZATION AND COMPOUND ANALYSIS

The FTIR analysis gives better information regarding the traces of all the compounds present in samples. The FTIR pattern of sample 1 has been given in Fig 2.3 (a). The band at 1031 cm\(^{-1}\) is due to C-N stretch and the bands at 1311.59 cm\(^{-1}\), 779.24 cm\(^{-1}\) and 653.87 cm\(^{-1}\) is for C-O stretch, C-Cl stretch and C-H bend respectively (Garcia et al., 1984). These bands prove the presence of calcium oxalate.

The FTIR pattern of sample 2 is given as Fig 2.3 (b) in which the bands at 2335.80 cm\(^{-1}\), 779.24 cm\(^{-1}\) and 559.86 cm\(^{-1}\) are for C-C stretch, C-Br stretch and alkyl halides and are the bands proves the presence of phosphate group (Carmona et al., 1980). In the FTIR spectrum, it has been observed that the sample contains the traces of para-hydroxy-triamterene (Cifuentes et al., 1986). This proves that the sample comes under the rare drug lithiasis category where the urinary stone formation has been triggered due to the intake of drugs containing triamterene. The triamterene is a major constituent of many of the high blood pressure medicines.

The FTIR pattern of sample 3 is shown in Fig 2.3 (c). The bands at 2916 cm\(^{-1}\) and 3209 cm\(^{-1}\) are due to the O-H stretch and C-H stretch respectively. The bands at 1246 cm\(^{-1}\) is due to C-N bend and these patterns very well prove the presence of phosphate in the sample (Carmona et al., 1980). Fig 2.3 (d) shows the FTIR spectrum of sample 4 in which the bands at 3473.80 cm\(^{-1}\), 1614.42 cm\(^{-1}\), 1313.52 cm\(^{-1}\) and 779.24 cm\(^{-1}\) are due to the O-H stretch, N-H bend, C-O stretch and alkyl halides respectively. The spectrum pattern has been reported before for urate monohydrate stones (Herring, 1962).

The Fig 2.3 (e) shows the FTIR spectrum of sample 5 in which the bands at 1606 cm\(^{-1}\), 1313.52 cm\(^{-1}\) and 653.57 cm\(^{-1}\) are due to C-C stretch, C-O stretch and C-H bend respectively. The pattern has been already reported for calcium oxalate monohydrate (whewelite) stone (Garcia et al., 1984). The spectrum shown in Fig 2.3 (f) is for sample 6. The bands at 2996.52 cm\(^{-1}\), 1651.07 cm\(^{-1}\), 1346.31 cm\(^{-1}\), 1120.64 cm\(^{-1}\), 989.84 cm\(^{-1}\) are due to C-H stretch, N-H bend, N-O symmetric stretch, C-N stretch and C-H bend respectively. These bands show the presence of calcium phosphate in the sample.
Fig 2.3: The FTIR patterns of (a) Sample 1 (b) Sample 2 (c) Sample 3 (d) Sample 4 (e) Sample 5 (f) Sample 6.
2.3.3 LASER LITHOTRIPSY PARAMETER ANALYSIS

2.3.3.1 STONE ABLATION RATE (SAR) ANALYSIS

Stone ablation rate is the main lithotripsy parameter where its value shows the relevance and efficiency of laser lithotripsy treatment. SAR is the rate at which the stone has been ablated by a given laser power during a fixed time period and has been calculated using the equation

\[
\text{SAR} = \frac{\text{Pre weight} - \text{Post weight}}{\text{Time}}
\]  

(2.1)

In this experiment the SAR has been calculated for all the samples by applying different laser power for a fixed period of time. Initially a power of 10 mW has been applied to the sample for time duration of 1 min which is given in Table 2.1.

Table 2.1: The SAR value of the samples when a laser power of 10 mW/ 1 min was applied

<table>
<thead>
<tr>
<th>SAMPLE NO</th>
<th>SAR (mg/sec) [mean ± SD]</th>
<th>Special Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.76 ± 0.776</td>
<td>----</td>
</tr>
<tr>
<td>2</td>
<td>4.53 ± 0.260</td>
<td>----</td>
</tr>
<tr>
<td>3</td>
<td>3.66 ± 0.165</td>
<td>High crater formed</td>
</tr>
<tr>
<td>4</td>
<td>0.863 ± 0.041</td>
<td>----</td>
</tr>
<tr>
<td>5</td>
<td>Smashed completely</td>
<td>Fragmented</td>
</tr>
<tr>
<td>6</td>
<td>6.10 ± 0.95</td>
<td>----</td>
</tr>
</tbody>
</table>
The sample 1 shows high SAR rate where the sample 4 shows the lowest SAR value. This shows that the sample 1 requires less power to fragment the stones whereas the sample 4 requires more power to get it fragmented. In the next case a power of 12 mW is applied to the samples for a time period of 1 min which is shown in Table 2.2. The sample 5 is broken into very small pieces which means a further breaking down is not possible. More specifically the surface area of the stone surface is lesser than the fibre tip (laser beam). This sample cannot be broken further down with laser beam.

Table 2.2: The SAR value of the samples when a laser power of 12 mW/min was applied

<table>
<thead>
<tr>
<th>Sample No</th>
<th>SAR (mg/sec) [mean ± SD]</th>
<th>Special Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24.3 ± 0.98</td>
<td>----</td>
</tr>
<tr>
<td>2</td>
<td>18.31 ± 1.70</td>
<td>----</td>
</tr>
<tr>
<td>4</td>
<td>1.83 ± 0.08</td>
<td>High crater formed</td>
</tr>
<tr>
<td>6</td>
<td>4.996 ± 0.335</td>
<td>----</td>
</tr>
</tbody>
</table>

In this case it has been observed that for all the samples the SAR value has been increased from the previous case which is because of the more laser power input. Hence the efficiency of fragmenting has been increased for 12 mW input than 10 W laser beams. The SAR value is high for sample 1 as in the previous case, and less for the sample 4 and sample 5.
The final session of the study is by applying a laser power of 17 mW for a time period of 1 min and the SAR values has been given in Table 2.3.

Table 2.3: The SAR value of the samples when a laser power of 17 mW/ min was applied

<table>
<thead>
<tr>
<th>SAMPLE NO</th>
<th>SAR (mg/sec) [mean ± SD]</th>
<th>Special Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.99 ± 0.83</td>
<td>----</td>
</tr>
<tr>
<td>2</td>
<td>9.99 ± 0.165</td>
<td>----</td>
</tr>
<tr>
<td>6</td>
<td>4.996 ± 0.335</td>
<td>----</td>
</tr>
</tbody>
</table>

In table 2.3, it has been observed that the SAR rate is drastically decreasing for the samples even for higher laser power. This pattern has been obtained for all the samples, hence can be concluded that the result is not related to the composition of the samples. This result proves that the optimum power of laser to be used for laser lithotripsy is from 10 mW to 15 mW. The power higher than this decreases the efficiency of the treatment since it damages the laser fiber; hence despite from the stone size and stone hardness, the treatment can be only operated at this low power. Therefore if the patients are prone to big stones, the treatment will stretch to multiple sitting which increases the cost of treatment.

The SAR results for all the cases been compared to prove that sample 1 i.e. calcium oxalate stones are easy to fragment even though it appears to be hard. The pure stone compositions require less power to break. The SAR values proved that sample 4 i.e guanidium urate monohydrate stone require more power. Urate derivative stone occur due to the inefficiency of purine metabolism and appears to be smooth in surface but requires more power to get it fragmented.
2.3.3.2 FIBRE TIP DEGRADATION RATE (FDR)

The fibre tip degradation rate shows the rate at which the tip of optical fibre degraded when it is used for the treatment. The cost of the treatment is high because the treatment uses laser source as well as optical fibres which are very costly. The optical fibre will degrade as its tip comes in contact with the stone, when laser light passes through it. The study has been done to monitor the fibre tip length when it was used for ablation study for various samples at different laser powers for duration of 1 min.

It has been observed that the FDR was 6 mm/min, 8 mm/min, 11 mm/min when a power of 10 W, 12 W and 17 W respectively. These FDR value has been constant for all the samples and hence can be proved that FDR depends only on the laser power used and time period. Hence the treatment cost will increase drastically with the number of sittings.

2.4 CONCLUSION

This chapter has been dealt with the in vitro study of laser lithotripsy to monitor the efficiency of this treatment. From the studies, it has been proved that the laser lithotripsy is not a cost effective treatment and cannot be used by all the societies. The person with comparatively bigger stone has to do multiple sitting as mentioned by this studies since the laser intensity cannot be increased above a certain range and this treatment is non invasive; therefore creates more of a discomfort to the patients.

The laser lithotripsy is not applicable for patients who have very large stones because ureteroscopy requires active removal of all or most stone fragments. The treatment of very large stones ( > 2 cm) may yield so many fragments, so that complete removal becomes impractical or impossible.

Laser lithotripsy treatment cannot be done for patients with a history of urinary tract reconstruction. The anatomy of patients who have undergone urethral or bladder reconstruction may not allow for passage of a ureteroscope. Likewise, this treatment is not applicable for patients who are intolerant of stents. These disadvantages prove the necessity of developing a next generation treatment modality for urolithiasis which can be more feasible and more comfort to the patients.