Journal of Advances in Medicine and Medical Research

24(7): 1-9, 2017; Article no.JAMMR.37701
ISSN: 2456-8899
(Past name: British Journal of Medicine and Medical Research, Past ISSN: 2231-0614, NLM ID: 101570965)

A Mini-Review of Shock Wave Lithotripsy and Its Role in Urological Treatment of Kidney Stones

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Authors' contributions

This work was carried out in collaboration between all authors. The review was designed and conducted by author JAM. The first draft of the manuscript was written by authors JAM, SFH and IS critically reviewed the manuscript and approved the final version. All authors read and approved the final version of the paper.

Article Information

DOI: 10.9734/JAMMR/2017/37701
Editor(s):
(1) Dean Markic, Assistant Professor, Department of Urology, University Hospital Rijeka, Croatia.
Reviewers:
(1) Kalima Nzanzu Adelard, Ruwenzori Official University, Republic of Congo.
(2) Ioan Magyar, University of Oradea, Romania.
(3) Baumann Johannes M., Switzerland.
Complete Peer review History: http://www.sciencedomain.org/review-history/22027

Mini-review Article

Received 25th October 2017
Accepted 19th November 2017
Published 23rd November 2017

ABSTRACT

Background: It is estimated that 1 in 11 people will experience symptoms for kidney stones within their lifetime, in which men are marginally affected more than women. As there are a range of treatment options available to treat kidney stones, it is important to understand surgical trends in relation to cost-effectiveness of each treatment, to allow the best advice to be given to the patient when deciding which treatment option is in their best interest.
Methodology: Common search engines were used including PubMed, Science Direct and Google Scholar, employing MeSH terms, including extracorporeal shock wave lithotripsy, kidney stones and complications. Specific search engine tools were used to narrow the range of publication to no more than 10 years old, and to favour review articles over common research articles to search for non-specific epidemiologic statistics.
Results: From 27 identified studies, 6 studies could be compared side by side covering a large

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range of populations including Australia, Canada, England, Korea and America. All regions saw an increase in incidence for kidney stones ranging from 0.37% to 4.37% per year. In addition, changes in elected treatment for saw significant changes for not only shock wave lithotripsy, flexible ureteroscopy and percutaneous nephrolithotomy saw increases and decreases respectively.

Conclusion: The rising incidence of kidney stones is attracting major attention in clinical and research areas, due to rising obesity, poor dietary habits and lack of adequate fluid intake across the world. Although the number of SWL procedures is decreasing, many studies show this is due to extensive knowledge about the limitations and complications of the procedure. Further research is anticipated to overcome current limitations for SWL treatment and therefore should be monitored in the future.

Keywords: Shock wave lithotripsy; kidney stones; clinical care.

ABBREVIATIONS

SWL : Shock wave lithotripsy
FURS : Flexible ureteroscopic surgery
PNCL : Percutaneous nephrolithotomy
BAUS : British Association of Urological Surgeons
NHID : National Health Incidence Data

1. INTRODUCTION

It is estimated that 1 in 11 people will experience symptoms for kidney stones within their lifetime, in which men are marginally affected more often than women. The incidence of kidney stones has been steadily increasing for many years, presenting a peak age of 45 years of age for the first stone incidence. Most stones form due to a combination of environmental and genetical factors with 22.1 million cases noted in 2015 and approximately 16,100 deaths [1,2]. Given the increased prevalence of kidney stones around the world it has drawn attention for more research into preventative methods and optimal treatment procedures. Currently patients undergoing treatment for kidney stones have a range of choices including: extracorporeal shock wave lithotripsy (SWL), flexible ureteroscopic surgery (fURS), and percutaneous nephrolithotomy/ stone removal (PNCL). All procedures have their own advantages and associated complications, which ultimately allow the patient to decide which treatment is preferred. As there are a range of treatment options available it is important to understand surgical trends and cost-effectiveness of each treatment, to allow the best advice to be given to the patient when deciding which treatment option is in their best interest.

Shockwave lithotripsy remains a very common form of treatment for kidney stones as the procedure is non-invasive and has a relatively high success rate ranging from 70-90%. It is also favourable as it relatively cheap in comparison with alternate procedures such as fURS and PNCL. However, the procedure does have associated complications, which occur in approximately 1/7 patients. Complications can be self-limiting or reversible, while others can have a detrimental effect on the patient (complications compiled from the British Association of Urological Surgeons (BAUS) are listed in Table 1). Incremental cost for post-operative complications for SWL averaged around £25,000 in comparison with other treatments £38, 000 for PNCL and £18, 000 for fURS [3,4]. These costs show there is a need to evaluate the development of post-operative complications via research of novel and common biomarkers, which could act as precursors for the more severe complications. Before employing a search strategy, it was important to identify specific areas of interest which include trends in surgical management, the current status of SWL in clinical care and practical steps to improve outcomes.

2. METHODOLOGY

2.1 Search Strategy

Common search engines were used including PubMed, Science Direct and Google Scholar. Specific search engine tools were used to narrow the range of publication to no more than 10 years old and to favour review articles over common research articles to search for non-specific epidemiologic statistics. These databases were searched with keywords and MeSH terms, for example: (“extracorporeal shock wave lithotripsy” [MeSH] AND “kidney stones” [MeSH] AND “globally”; “complications” [Subheading] OR “intraoperative complications” AND/OR

"postoperative complications") for general searches for global statistics for SWL treatments. Other more specific searches were also used for example: ("extracorporeal shock wave lithotripsy [MeSH] AND "kidney stones" [MeSH] AND "status of clinical care" [Subheading] OR "recent clinical care" [MeSH] AND "complications" [MeSH] AND/OR "intraoperative complications" AND/OR "postoperative complications" AND/OR "alternate treatment" [MeSH]). Searches were conducted between the 3rd July 2017 and 31st August 2017. There was no language restriction. A total of 120 published papers were identified as potential targets once the search had been conducted and the abstract had been read. Of the 120 target papers, 27 were identified that contained sufficient information that conformed with the search terms.

2.2 Analysis Methods and Definitions

As with most hospital-based studies, gathering information relating to complications is usually retrospective and record-based, this poses a common problem when collating information regarding post-operative complications following SWL. As most patients experience mild post-operative complications that can be resolved by 'over the counter' medications these studies have a tendency to under-estimate the precise number of cases. The studies selected were analysed using year of publication, the number of patients reviewed over time, area of the world where the study was carried out and presentation of results. Definitions of complications differed between studies, to allow conformity between studies. The BAUS guidelines for post-operative complications were used to exclude studies that presented post-operative complications that were not mentioned (Table 1). In addition, further studies were excluded which represented post-operative complications, which were present via human error i.e. damage to surrounding tissues because of shockwaves missing the target stone. Trends in surgical management and the current status of SWL in clinical care are defined by statistics comparing SWL to other procedures. Any changes in procedure numbers or renal admissions are expressed as percentage change, over the time-period tested and the number of patients in the study.

3. RESULTS

From the 120 target papers, only 27 included sufficient information of which 6 were in a format to compare the studies. In addition, several studies did present information in a comparable format but lacked statistics from a wider area or time-period, which could be subject to specific genetic and environmental bias and were therefore excluded as the results would not be representative of whole populations. A study from Brazil [6] was also removed from the statistical analysis as no shock wave results were reported. However, it was clear that this study was observing a developing medical service as fURS and PNCL treatments saw significant increases of 607% and 792% respectively. The lack of SWL data may point to the lack of development in SWL making the procedure inaccessible to larger proportions of the public.

Table 1. List of potential complications that may arise after extracorporeal shock wave lithotripsy for the treatment of kidney stones [5]

Complication	Severity	Statistics
Blood in the urine. Pain in the kidney as small fragments pass. Need for further lithotripsy treatment. Failure to break stone resulting in alternative treatment. Recurrence of stones in the future.	Normal	Between 1/2 and 1/10 patients.
Infection of the urinary tract. Bruising or blistering of the skin at the site of shockwave entry or exit. Some fragments may lodge in the ureter requiring surgical removal.	High	Between 1/2 and 1/50 patients.
Severe infection requiring injected antibiotics or nephrostomy. Kidney damage with severe bruising. Inadvertent damage to the pancreas or lungs.	Severe	Between 1/50 and 1/250 patients.

Although the prevalence of kidney stones is constantly changing the reviewed papers all reported an increase across their respective populations: Canada reported an average year by year increase of 2.71% over a 19 year period studied (194, 781 patients reviewed); the US reported an average year by year increase of 0.37% (Census, 109,455 patients reviewed) and 3.08% (Medicare 115,200 patients reviewed) over the 10 and 9 year studies respectively; England reported an average year by year increase of 3.53% over the 15 year period studied (86,742 patients reviewed); Korea reported an average year by year increase of 4.37% over the 10 year period studied (14, 282 patients reviewed) and Australia reported an average year by year increase of 3.90% over the 14 year period studied (169,954 patients reviewed), data is presented in Fig. 1 [7-13].

The reviewed papers also presented data that favoured fURS over SWL treatment: Canada reported a 35% decrease in SWL, 34% increase in fURS and no changes were reported for PNCL; the US reported a 5.2% using National Health Incidence Data (NHID) and 33.6% (Medicare) increase in SWL, 11.5% (NHID) decrease and 65.2% (Medicare) increase in fURS and a 14.7% (NHID) and 1.2% (Medicare) increase in PNCL; England reported a 66.5% increase in SWL, 66.5% increase in fURS and a -89% decrease in PNCL; Korea reported an increase of 43.7% in SWL, 31.9% increase in fURS and 87.5% increase in PNCL finally, Australia reported a 3.5% decrease in SWL, 9.3% increase in fURS and a 6.4% decrease in PNCL presented in Fig. 2 [7-13].

4. DISCUSSION

4.1 Trends in the Prevalence of Kidney Stones

It is important to consider that the composition and formation of kidney stones are heavily affected by diet, lifestyle and additional disorders or diseases such as diabetes. These factors vary from population to population resulting in fluctuating prevalence rates between different regions of the world [14,15]. As a result of increasing life expectancy, rising obesity, poor dietary habits and lack of adequate fluid intake, studies were looked at from around the globe

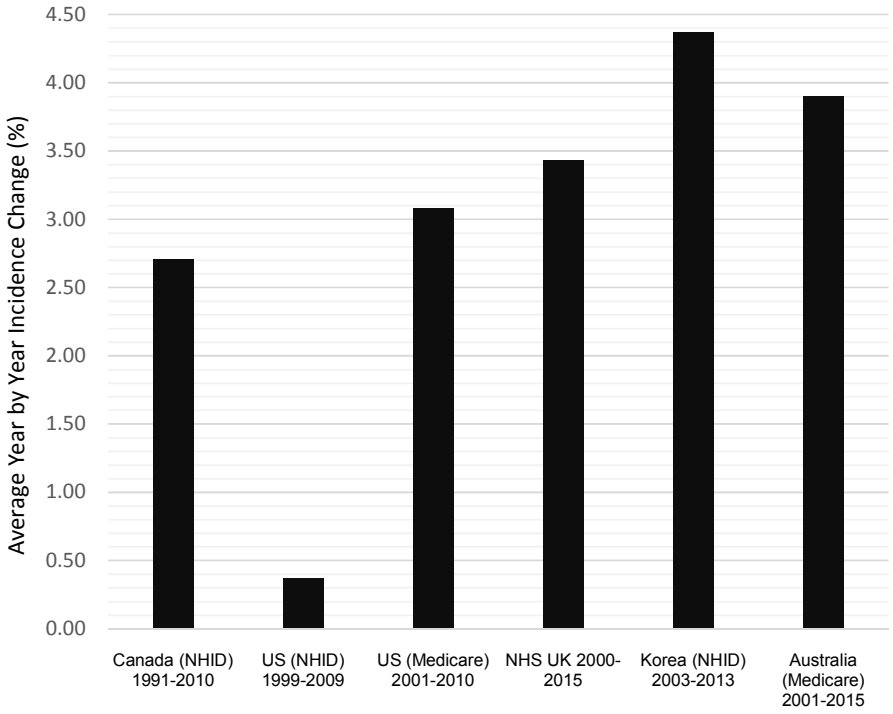

Fig. 1. Year by year incidence rate (%) across the world, calculated by percentage change of total cases for kidney stones [7-13]

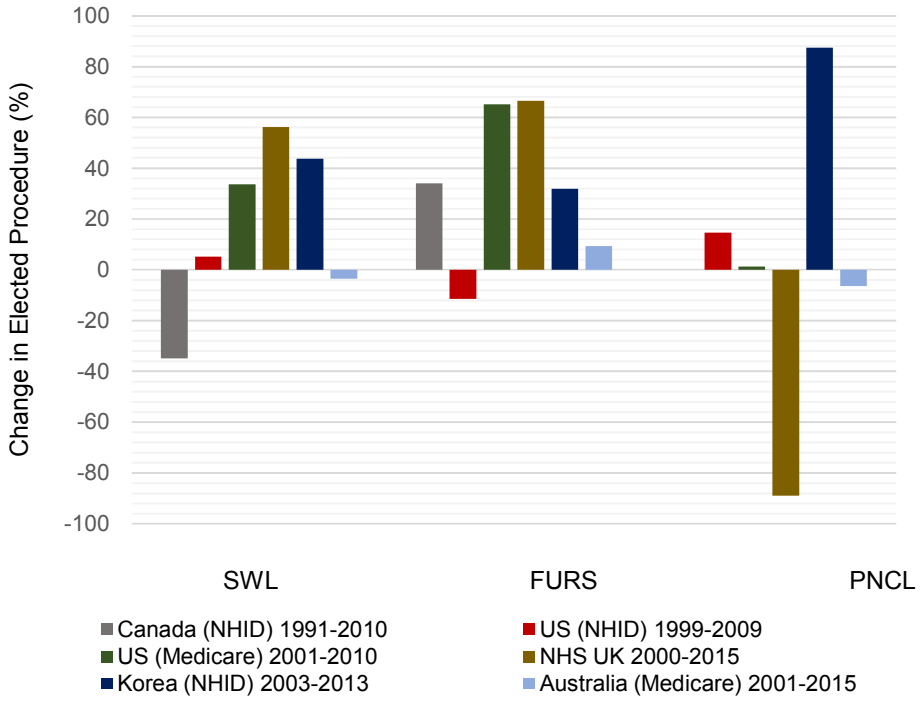

Fig. 2. Change (%) in SWL, fURS, and PNCL procedures for treatment of kidney stones [7-13]

including Australia, Canada, England, Korea, and USA. Two studies were observed at from Australia, spanning from 1995 until 2015, both studies demonstrated significant increases in procedures undertaken for the treatment of kidney stones. Between 2001-2015 the number of procedures increased from 79,538 to 169,954 [13]. In addition, between 1995 and 2010 it is reported there was an increase from 4,842 to 11,849 [16]. Both studies highlight the need for a consensus on stone treatments within Australia, but little to no reasons why are reported.

North America and Canada demonstrate similar results, reported statistics from a nationwide inpatient sample spanning, 1999-2009 showed an overall of 2,109,455 patients were hospitalised with upper urinary tract calculi. What is interesting about these statistics is the admission numbers rose by 12%, but the discharges remained stable indicating longer stays in hospital. Furthermore, more women than men were admitted, which is not shown in nationwide statistics and significant increases in black, Hispanic and older patients. Data presented here, may point towards different diet and lifestyles of these groups, and some may favour the formation of kidney stones [8]. In comparison from another study in America over a 10-year period, there were 115,200 surgeries with an increase in patients diagnosed with ureteric calculi from 57,120 to 90,660 [9]. This study also presented data that the number of discharges remained relatively stable suggesting locoregional, racial and gender bias selection of treatment. Canada also showed similar increases in prevalence from 85,000 to 126,000 between 1991-2010 [7], this study did observe more men than women being treated 63.22% and 36.78% respectively, but no report of gender or ethnic bias. As expected urban areas had a higher percentage of treatments than rural areas 87.54% and 12.46% respectively representing no locoregional bias.

Studies from the UK follow the global trend, in fact NHS statistics showed a subtler increase in upper urinary treat stone hospital episodes from 51,035 to 86,742 between 2000 and 2015 [10, 17]. Similarly, the studies in Canada and the US report increased prevalence levels, which may suggest that a significant rise in obesity and metabolic syndromes may be a causal factor. However, the UK differs in the length of hospital stay compared to the rest of the world, the UK opted to introduce more day-case managements, which could skew average year-by-year incidence as more cases can be undertaken in

comparison with the US data. In addition, there was a lack of studies from the continent of Asia that met the criteria set by the search queries, however one recent study was reviewed. In Korea presented statistics for 14, 282 patients received treatment for kidney stones over a 10-year period, which saw the number of cases per year double from 1,036 to 2,106 [11]. This follows global trends of increasing prevalence, it is also predicted with an increasingly westernised diet, more sedentary lifestyle and increase in obesity the prevalence of kidney stones will rise in years to come.

4.2 Trends in the Treatment Method for Kidney Stones

Trends in the treatment of kidney stones have changed considerably over the past 30-40 years, since the introduction of flexible ureteroscopy in 1964, and electrohydraulic lithotripsy and discovery of ultrasound destruction of kidney stones in 1953-4. With the increased prevalence across the world significant improvements have been made in the management of urinary stones disease and have assisted in reducing renal damage and related renal failure [18]. Non-invasive SWL had become the predominant treatment modality after its discovery, with ureteroscopy utilized only for lower ureteral stones and PNCL used for very serious cases. However, more recently there has been a regression in SWL treatments due to the advances in fURS, although both fURS and SWL appear viable procedures, stone location and composition in addition to patient characteristics play a large role in the decision in electing the optimal treatment [19]. fURS are favoured for larger stones ranging between 10-20 mm as well as obese patients where skin to stone distance would reduce the efficacy of SWL severely.

Although all papers reviewed in this article show an increase in incidence, the figures for elected procedure differ dramatically. Two studies shown (Fig. 2.) that represent the US showed different changes in all elected procedures [8,9]. Using US nationwide inpatient samples ureteroscopy saw an 11.5% decrease in comparison with SWL which saw a 5.2% increase. In addition, transurethral removal of obstruction from ureter and renal pelvis and ureteric catheterisation did significantly increase by 14.7%. The observations showed that PNCL was the main inpatient surgical intervention for renal calculi, although in comparison with fURS and SWL it is relatively low in terms of procedure numbers. It was also observed that SWL was favoured over fURS, although no major changes were recorded reflecting the improvement of day case procedures for treatment of kidney stones [8]. These results differed completely in comparison with Medicare statistics for the US which saw increases across the board: 33.6% for fURS, 65.2% for SWL and 1.2% for PNCL. Multiple variables were used to explain the increasing trends for fURS and SWL but most mainly came down to physician bias towards a specific procedure and different styles of practice. The major increase in SWL was suggested to be because of the older demographic had a lower probability of undergoing surgical treatment. This would lead to better health, increased spontaneous stone passage and significantly lower health costs [9]. On the other hand, Canada saw more varied results with a 35% decrease in SWL treatments and a 34% increase in fURS treatments, surprisingly there was consistent readmissions following fURS compared to SWL which was not seen in the US studies. This may be due to a larger number of fURS treatments being undertaken in comparison with SWL [7].

The NHS UK also reported similar increases in fURS treatment observing a 66.5% increase between 2000 and 2015, in addition SWL saw a larger increase than that of the US observing a 56.2% increase between 2001 and 2010. Interestingly PNCL saw a dramatic decrease of 89% this shows that day-case procedures are favoured over surgical procedures. This may be because of ever increasing demand on the NHS to provide a service to an aging population, but also a lack of funding within the NHS, leading to cheaper alternatives being elected over surgical procedures [10,17]. The rise of mobile SWL has helped access less mobile patients, although this has reduced the utilization of SWL for more serious or emergency cases. In turn, it is expected that fURS will overtake SWL as the more common method of treating kidney stones in the coming years. Compared to fURS and SWL, PNCL is a much more time consuming and complicated procedure and with the lack of specialist personnel from multiple departments the decrease in PNCL was to be expected [10].

In comparison, Korea showed increases in fURS, SWL and PNCL by 43.7%, 31.9% and 87.3% respectively between 2003 and 2013. SWL dominated in primary treatment, reasons for this are justified from the significant use of private practice by urologists that own SWL equipment

and do not perform fURS. The study also shows that sociodemographic factors have a significant effect on primary and therefore secondary treatments, which is also seen in the US. It was observed that patients living in urban or suburban areas were significantly less likely to undergo URS and PNCL. The significant rise in PNCL was due to a rise in larger/multiple more complicated stones, with a greater likelihood of recurrence [11]. Finally, Australia showed an increase in fURS by 9.3% but SWL and PNCL decreased by 3.5% and 6.4% respectively between 2001 and 2015, in comparison with the rest of the world the change in practice is not significant however the world trend is followed with fURS being favoured for the treatment of kidney stones [13].

4.3 Status of SWL in Clinical Care

Current advancements in SWL have improved its safety and efficacy, but the limitations and drawbacks remain. The need for retreatment in most cases is necessary which most patients do take into consideration. Also with the development of flexible devices that can be used in a day case setting patients that would previously opt in for SWL treatment may now favour fURS. SWL still represents a unique non-invasive treatment method with little to no anaesthesia and relatively low complication rates. However, the number of patients willing to accept the risk of a failed treatment and a second procedure, for the trade-off for less instrumentation is surprising [20,21]. The reported success rates for stones up to 15mm is around 78.6% after 3 months of follow up with most patients preferring SWL over other procedures [3]. However, results can vary by large proportions, this is a direct result of established criteria regarding stone composition and patient features [22].

Further studies have considered minor variables that could affect the clinical outcome, in one study model defects were placed in the coupling gel that is needed to prevent shocks passing through the air which reduces the efficacy of the procedure [23]. It was shown that stone breakage decreased in the proportion to the area of the coupling defect. Blocking the transmission of shock wave energy prevents stone breakage but also the focal width showing that the coupling gel can be a seriously limiting factor if not applied correctly. In addition, it has been shown that step wise power ramping used to 'acclimatise' the tissue before shock wave therapy commences has resulted in less tissue trauma than starting the therapy abruptly. Slowing the firing rate to 60 shocks per minute or slower has been effective at reducing renal injury. Furthermore, using high oxygen flow in addition with dual slow shock wave ramping has also shown promising developments for improving clinical outcomes [24,25]. On the other hand, measures such as double J stenting was used to assess whether clinical outcomes for treating 1 to 2cm stones could be treated with SWL presented adverse effects showing reduced clearance of stones and making the later course of the recovery uncomfortable [26].

Aside from physical changes that can be made to the procedure method other research has been carried out to try and improve clinical outcomes. Research into anxiety, depression and stress having a possible effect on SWL treatment. However, no statistical differences were recorded, which had no effect on pain scores given by the patient after the procedure regardless of patient age, sex, side of stone, presence of double J-stent or number of stones [27,28]. Further studies have found that losartan has shown significant effects on reducing albuminuria after 1 week and renal perfusion in patients with obstructed kidneys in comparison to before SWL [29]. It was also observed that losartan and verapamil maintained renal perfusion in patients with post SWL renal obstruction showing potential for therapeutic treatment to improve clinical outcomes before and after treatment. A pilot study looking at the haemostatic function following SWL has shown promising changes in platelet count, fibrinogen concentrations and von Willebrand factor. This study shows how the 'normal' response following SWL needs to be reviewed with the potential that a simple blood test may be able to predict post-operative complications [30,31].

5. CONCLUSION

In conclusion, the rising incidence of kidney stones is attracting major attention in clinical and research areas, due to rising obesity, poor dietary habits and lack of adequate fluid intake across the world. Although the number of SWL procedures is decreasing many studies show this is due to extensive knowledge about the limitations and complications of the procedure. Despite this, SWL remains at the forefront of novel research showing constant improvement, enhanced clinical outcomes and reduced hospital stays over the past 10 years, which will keep

patients opting for SWL as a primary treatment for kidney stones. Further research is anticipated to overcome current limitations for SWL treatment and therefore should be monitored in the future.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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