The Surgical Management of Kidney Stone Disease in the Province of Ontario: A Population Based Time Series Analysis

by

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A thesis submitted in conformity with the requirements for the degree of Masters of Science in Clinical Epidemiology

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University of Toronto

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Master’s Degree in Clinical Epidemiology

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Abstract

A population based cross-sectional time series analysis was conducted using three Ontario administrative databases, to assess trends over time in the surgical management of kidney stone disease. All kidney stone treatments performed with extracorporeal shockwave lithotripsy (SWL), ureteroscopy (URS) and percutaneous nephrolithotomy between July 1, 1991 and December 31, 2010, were included. Time series modeling with exponential smoothing and autoregressive integrated moving average models demonstrated a significant increase in the utilization of URS over time (23.69% to 59.98%, p<0.0001), with a reciprocal significant decrease in the utilization of SWL (68.77% to 33.36%, p<0.0001). As a result of this shift in treatment paradigm, time series modeling also demonstrated an associated significant decrease in the need for ancillary treatment over time (22.12% to 16.01%, p<0.0001) and a significant increase in the need for hospital readmission (8.01% to 10.85%, p<0.0001) or emergency room visit (7.58% to 9.95%, p=0.0024) within 7 days following treatment.
Acknowledgements

There are a number of people whose contributions made this thesis possible and deserve mention. I would like to thank my supervisor David Urbach whose knowledge of non-experimental design and health services research proved instrumental in designing and carrying out this study.

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Chapter 1- Introduction & Study Objectives

1.1 Rationale

Nephrolithiasis is a very common disease, with an increasing incidence and prevalence\(^1\)\(^{-6}\), and a significant economic impact associated with its treatment\(^7\). The surgical management of kidney stone disease has changed dramatically over the past 25 years, as a result of revolutionary technologic and treatment advances. In particular, ureteroscopy (URS) has been significantly impacted, by these advances.

In light of these technologic improvements, the literature suggests that over time URS become more efficacious\(^8\)\(^{-10}\), associated with less complications\(^10,11\) and a more accessible and commonly used modality than before\(^12\). However, the studies demonstrating increased utilization of URS have been predominantly based on physician surveys\(^12,13\) and or retrospective series from single centres\(^10,11,14\). More importantly, although numerous studies\(^10,11,15\) and even a meta-analysis\(^16\) have shown a high success rate and low complication rate with modern URS, these studies have largely been completed at high volume centres with technical expertise. However, many centres may lack the technologically up-to-date equipment and technical expertise necessary to achieve these results.

At present, large population based evaluations have not been conducted to accurately assess:

- The trends over time in the utilization of different treatment modalities in management of kidney stone disease.
• The subsequent effect of these trends and technologic advances on patient morbidity in the “real world”, including the need for repeat or auxiliary treatment.

Our aim was to examine surgical treatment trends over time for nephrolithiasis, in the province of Ontario. Administrative databases, within the context of the universal healthcare system in Ontario, provided an excellent opportunity to study this at a population level.

1.2 Study Objectives

**Primary**


2. To determine if the need for repeat or auxiliary treatment and morbidity from kidney stone procedures has changed significantly over this same time period, in the province of Ontario.

**Secondary**

1. To describe the demographics (age, gender, socioeconomic status) of patients undergoing kidney stone treatment in the province of Ontario over the past 20 years.

1.3 Study Hypotheses

1. The utilization of URS in the surgical management of kidney stone disease has increased significantly over the past 20 years, in the province of Ontario.
2. The hypothesized increased use of URS has resulted in a significant decrease in repeat or auxiliary treatments, but an increase in patient morbidity from kidney stone treatment.
Chapter 2- Background

2.1 Pathophysiology of Kidney Stone Disease

2.1.1 Definition and Pathogenesis

Kidney stones are a crystal aggregation formed in the kidneys from dietary minerals in the urine. The physical process of stone formation is a complex cascade of events. It begins with urine that becomes supersaturated with stone-forming salts (e.g., calcium, oxalate, uric acid, magnesium, phosphate) resulting in their precipitation out of solution to form crystals. Once formed, crystals may flow out with the urine or be retained in the kidney at anchoring sites that result in growth and aggregation, ultimately leading to stone formation\textsuperscript{17}.

Once a kidney stone has formed it may continue to reside in the collecting system of the kidney (renal pelvis or calyx) or pass into the ureter, the tube draining urine from the kidney to the bladder (Figure 2.1 & 2.2). Stones that remain in the kidney, known as renal calculi, may continue to grow in size or remain stable. Most commonly renal calculi will remain asymptomatic, unless they become lodged at the junction of the kidney and ureter (ureteropelvic junction). Conversely, the majority of stones that pass into the ureter (i.e., ureteral calculi) will result in a significant amount of pain, referred to as renal colic. Renal colic is characterized by constant flank pain and intermittent pain radiating from the flank towards the groin. The intense pain is often accompanied by nausea and vomiting.
Figure 2.1. Genitourinary Tract Anatomy
2.1.2 Composition

Kidney stones can be classified based on their composition. In broad terms, stones are usually classified into calcium containing and non-calcium containing stones (Table 2.1). Calcium containing stones include calcium oxalate, hydroxyapatite and brushite (calcium phosphate) stones. Non-calcium containing stones include uric acid, struvite,
cysteine and medication related stones (Triamtrene, Silica). Calcium oxalate stones are the most common and make up 60% of all stones.

<table>
<thead>
<tr>
<th>Stone Composition</th>
<th>Occurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calcium containing</strong></td>
<td></td>
</tr>
<tr>
<td>Calcium Oxalate</td>
<td>60</td>
</tr>
<tr>
<td>Hydroxyapatite</td>
<td>20</td>
</tr>
<tr>
<td>Brushite</td>
<td>2</td>
</tr>
<tr>
<td><strong>Non-calcium containing</strong></td>
<td></td>
</tr>
<tr>
<td>Uric acid</td>
<td>7</td>
</tr>
<tr>
<td>Struvite</td>
<td>7</td>
</tr>
<tr>
<td>Cystine</td>
<td>1-3</td>
</tr>
<tr>
<td>Medications related</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

*Occurrence (%) referenced from Pearle MS, Pak YC. Renal calculi: a practical approach to medical evaluation and management.

2.1.3 Pathophysiology

Numerous pathophysiologic processes contribute to stone formation and differ based on the stone composition. In the case of calcium stone formation the pathophysiologic processes include hyperparathyroidism, increased gastrointestinal calcium absorption, chronic diarrheal syndromes, distal renal tubular acidosis, thiazide diuretics and primary hyperoxaluria, among many others. Alternatively, uric acid stones form exclusively in acidic urine typically with a pH ≤ 5.5, which can result from a diet high in animal protein or diarrheal states. In addition, both calcium containing stones and uric acid stones can form as a result of inadequate fluid intake/low urine volume. Cystine stones form as a result of impaired renal reabsorption of cystine due to an inherited autosomal recessive disorder. Lastly, struvite stones, also known as infection stones, develop in alkaline urine produced by certain bacterial infections of the urine (i.e., urease-producing bacteria).
2.2 Epidemiology of Kidney Stone Disease

Kidney stone disease is common with a lifetime prevalence estimated at 1% to 15%\textsuperscript{17}. The probability of developing kidney stones varies according to numerous factors including age, gender, race, geographic location and body mass index. Several studies support an increasing incidence and prevalence of stone disease in numerous countries around the world\textsuperscript{1-6}. This increase is hypothesized to be mainly due to environmental factors such as dietary habits and lifestyle, particularly an increase in the consumption of animal protein. In addition, improvements in clinical-diagnostic procedures, specifically radiologic imaging, have likely also contributed.

2.2.1 Age

Kidney stone disease is relatively uncommon before the age of 20, but the incidence rises rapidly and peaks from 40-60 years of age and then declines from 65 years of age and beyond \textsuperscript{6,19-22}. The prevalence of kidney stone disease increases with age up until the age of 70, at which point it begins to decrease\textsuperscript{6,22}.

2.2.2 Gender

Typically, kidney stone disease affects males more commonly than females. Based on studies that have examined inpatient admissions, outpatient clinic visits and emergency department visits, men are approximately two to three times more frequently affected than females\textsuperscript{7,22,23}. However, two recent studies provide evidence that this difference is narrowing\textsuperscript{1,24}. Scales et al. (2005)\textsuperscript{24}, demonstrated, using hospital discharge
data, that the prevalence, by gender, of treated stone disease decreased from a 1.7:1 to a 1.3:1 male-to-female ratio, from 1997 to 2002.

### 2.2.3 Race/Ethnicity

Several studies have reported differences in the prevalence of stone disease across race/ethnicity. In the United States (US), studies have shown a higher prevalence of stone disease in whites as compared to Hispanics, Asians and African Americans. Outside of the US, individuals of Arabic, West Indian, West Asian and Latin American origin have been shown to have a higher relative risk for calcium stones disease relative to Caucasians, while those of East Asian and African descent have been shown to have a lower risk.

### 2.2.4 Geography

A higher prevalence of stone disease is typically found in hot, arid, or dry climates such as the mountains, desert, or tropical areas, as geographic variability tends to reflect environmental factors. Previously, it has been reported that areas of high stone prevalence include the US, British Isles, Scandinavian and Mediterranean countries, northern India and Pakistan, northern Australia, Central Europe, portions of the Malay peninsula, and China.

### 2.2.5 Body Mass Index

The association between body mass index (BMI) and risk for stone disease has been demonstrated in two large prospective cohort studies. These two studies revealed that the prevalent and incident risk of stone disease were directly correlated with
weight and BMI in both sexes, however the magnitude of the association was greater in women than men\textsuperscript{27,28}.

2.3 Current Management of Kidney Stones

2.3.1 Indications for Treatment

Many patients with renal or ureteral calculi will not require intervention. Small (<5mm), non-obstructive, asymptomatic renal calculi generally do not require prophylactic treatment. Exceptions to this include pediatric patients, patients with a solitary kidney, patients in high-risk professions (e.g., pilots), and women considering pregnancy\textsuperscript{29}. For ureteral calculi, if the width is ≤5mm then approximately 68\% will pass spontaneously, and as such conservative management should also be considered in these patients\textsuperscript{29}.

Conversely, intervention is indicated for renal or ureteral stones unlikely to pass spontaneously, or for stones associated with intractable or intolerable symptoms, urinary tract infection or obstruction of the affected kidney. Furthermore, ureteral stones given a trial of conservative management that do not pass spontaneously will require surgical intervention.

2.3.2 Determinants of Treatment

A number of factors must be considered to determine the optimal treatment for patients with renal or ureteral calculi. These factors may be grouped into four broad categories: stone factors (location, size, composition, obstruction and duration of presence), clinical factors (symptom severity, patient’s expectations, associated infection,
obesity, coagulopathy, hypertension and solitary kidney), anatomic factors (horseshoe kidney, ureteropelvic junction obstruction, renal ectopia) and technical factors (available equipment, expertise, cost). When intervention is indicated, considering all of the above factors, the primary goal is to select the treatment that will achieve maximal stone clearance with minimal morbidity to the patient. In many cases more than one treatment option will be suitable and the ultimate treatment decision will be based on the patients preferences with respect to the balance between invasiveness and morbidity of the procedure versus the likelihood of achieving stone-free status. Access to necessary equipment and technical expertise may also play a key role in the treatment options offered to patients.

2.3.3 Surgical Management

Three main modalities are presently utilized in an attempt to achieve the goal of maximal stone clearance with minimal morbidity to the patient. These are extracorporeal shockwave lithotripsy (SWL), URS and percutaneous nephrolithotomy (PCNL). Each modality along with its indications for use is described below.

Treatment outcomes for these modalities are typically reported by two different terms: stone-free rate and success rate. Stone free means the absence of any radiological evidence of stone, whereas success includes patients who are stone free, as well as those with clinically insignificant residual fragments. The lack of consensus regarding the definition of clinically insignificant residual fragments makes comparisons across studies with this definition difficult. As such, for consistency only the stone-free rates have been reported below in describing each of the three modalities.
**Extracorporeal Shockwave Lithotripsy**

SWL involves the generation of relatively weak, non-intrusive shockwaves externally that are transmitted through the body. The shockwaves build to sufficient strength only at the target (i.e., the stone) where they generate enough force to fragment the stone. SWL is an outpatient procedure performed under conscious sedation, and doesn’t require a general anesthetic. It represents the least invasive of three surgical options for the management of kidney stone disease, but also the least effective at achieving stone-free status, in certain situations.

**Indications for Extracorporeal Shockwave Lithotripsy**

**Renal Calculi**

The majority of renal stones (50-60%) will be $<10\,\text{mm}$ in diameter and amenable to treatment with SWL. Treatment results from SWL for these patients are quite good (stone free-rate ~80%) and SWL is associated with minimal morbidity.

For renal stones between $10-20\,\text{mm}$, SWL can still be considered first line treatment unless factors of stone composition, location or renal anatomy suggest that a more optimal outcome may be achieved with a more invasive treatment modality (URS or PCNL). Studies have shown that SWL results for patients with $10-20\,\text{mm}$ stones in the lower pole are inferior (55%) to SWL results for patients with stones in the upper and middle pole calyces (71.8% and 76.5%, respectively). Furthermore, data from a randomized controlled trial (RCT) supports greater stone-free rates with PCNL compared to SWL for lower pole calculi.

Patients with renal calculi $>20\,\text{mm}$ who are treated with SWL monotherapy commonly experience poor treatment outcomes with stone-free rates $<50%$. So
although SWL is a treatment option, patients must be aware of the need for multiple procedures to achieve success and the potential for poor outcomes.

In addition to size and location within the kidney, stones composition and body habitus have been identified as factors associated with poorer SWL outcomes\textsuperscript{32,33}. Specifically, cystine, calcium oxalate monohydrate, and brushite stones are more resistant to fragmentation with SWL\textsuperscript{32} and obesity can inhibit imaging and targeting of the stone.

Lastly, SWL is generally reserved for the treatment of radiopaque stones, as targeting of the shockwaves is achieved with fluoroscopy. As such, radiolucent stones such as uric acid calculi are often not amenable to SWL.

\textit{Ureteral Calculi}

SWL is considered a first line treatment option for ureteral stones at all levels of the ureter (distal, mid and proximal). Based on a recent meta-analysis the stone-free rates in the proximal and mid ureter are not significantly different between SWL and URS\textsuperscript{8}. However, for proximal stones SWL had a higher stone-free rate for stones <10 mm, but a lower stone-free rate for stones >10 mm, as compared to URS\textsuperscript{8}. In addition, SWL yielded worse stone free rates for distal stones compared to URS. Furthermore, stone-free rates are lower and the number of procedures necessary to achieve stone-free status are higher for ureteral stones >10 mm in diameter, at any level, managed with SWL as compared to URS\textsuperscript{8}. Generally speaking, to achieve similar stone-free rates to URS a greater number of procedures is often required with SWL\textsuperscript{8}.

A summary of representative success rates for SWL in the treatment of ureteral stones is listed in Table 2.2.
Table 2.2. Stone-Free Rate for SWL and URS in the treatment of ureteral calculi

<table>
<thead>
<tr>
<th>Stone Location/Size</th>
<th>Stone Free Rate*</th>
<th>SWL</th>
<th>URS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distal Ureter</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤10mm</td>
<td>74%</td>
<td>94%</td>
<td></td>
</tr>
<tr>
<td>&gt;10mm</td>
<td>86%</td>
<td>97%</td>
<td></td>
</tr>
<tr>
<td><strong>Mid Ureter</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤10mm</td>
<td>73%</td>
<td>86%</td>
<td></td>
</tr>
<tr>
<td>&gt;10mm</td>
<td>84%</td>
<td>91%</td>
<td></td>
</tr>
<tr>
<td><strong>Proximal Ureter</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤10mm</td>
<td>82%</td>
<td>81%</td>
<td></td>
</tr>
<tr>
<td>&gt;10mm</td>
<td>90%</td>
<td>80%</td>
<td></td>
</tr>
</tbody>
</table>

*Stone free rate following first treatment or primary treatment is reported
**Stone free Rates from AUA/EAU 2007 Guidelines for the management of ureteral calculi

Ureteroscopy

URS involves the use of small semi-rigid or flexible endoscopes to treat stones under direct vision both in the ureter and kidney. When small enough, stones can be removed intact, but when larger they are typically fragmented with an energy source and the fragments extracted. Most commonly the holmium:YAG laser is utilized as the energy modality to fragment larger stones. URS is performed as an outpatient procedure typically under a general anesthetic. URS is considered more invasive and slightly more morbid than SWL, but with a greater likelihood of achieving stone-free status after a single procedure.

Indications for Ureteroscopy

Renal Calculi

URS can also be considered a first line treatment option for renal stones <10 mm in diameter and for stones between 10-20 mm in diameter. In particular, URS is favored when stone composition or location are associated with a poor SWL outcome, as discussed above.
For renal stones >20 mm, PCNL is traditionally the preferred technique in light of its high success rate. However, several case series and retrospective reviews have shown that URS is an effective option for patients with contraindications to (e.g., coagulopathy) or preference against PCNL. In these studies, the stone-free rate with URS, for renal stones >20 mm, ranged from 60-73.9%. Of note, for these larger stones most patients will require multiple procedures to achieve stone-free status.

**Ureteral Calculi**

Along with SWL, URS is considered a first line treatment option for ureteral stones at all levels (distal, mid and proximal). URS has been found to have similar or higher stone-free rates to SWL, except for proximal ureteral stones <10 mm. However, importantly URS typically requires fewer procedures to achieve these rates.

As previously detailed, certain stone compositions and large body habitus are associated with poor SWL outcomes and as such URS is specifically indicated for these ureteral stones. Furthermore, URS is favored when SWL is contraindicated. For example, ureteroscopy can be performed safely in select patients in whom cessation of anti-coagulants is considered unsafe.

Representative success rates for ureteroscopic management of ureteral calculi can be found in Table 2.1.

**Percutaneous Nephrolithotomy**

PCNL involves the removal of kidney stones through a small tract, which is dilated in the flank. This procedure is typically reserved for the larger and more complex (branching) renal stones. Once a tract is created both rigid and flexible endoscopes are used in conjunction with one of several intracorporeal lithotripters to fragment and
remove the stone burden. PCNL is done under a general anesthetic, commonly with the patient in a prone position and is an inpatient procedure. PCNL represents the most invasive of three modern surgical stone procedures, with the greatest risk for post-operative morbidity. However, it also has the highest success rates for large and complex renal calculi.

**Indications for Percutaneous Nephrolithotomy**

**Renal Calculi**

PCNL is indicated for the treatment of renal stones >20 mm, including the treatment of staghorn calculi. A staghorn calculus is a renal pelvic stone with extension into the renal calyces and most commonly is composed of struvite. The stone-free rates for non-staghorn calculi are excellent approaching 90%. For staghorn calculi, which are more complex to treat, the stone free rate remains high at 84%. PCNL is also an option for the treatment of renal stones between 10-20mm when located in a lower pole calyx as it has been shown to have high degree of efficacy compared to SWL, with acceptable morbidity.

**Ureteral Calculi**

Percutaneous antegrade removal of ureteral stones is a consideration in selected cases. For example, in the treatment of very large (>15 mm diameter) impacted stones in the proximal ureter between the ureteropelvic junction and the lower border of the fourth lumbar vertebra. In such cases the stone-free rate is reported between 85-100%. Percutaneous antegrade removal of ureteral stones is also an alternative when SWL or retrograde URS has failed or when the upper urinary tract is not amenable to retrograde URS and SWL is not indicated.
Summary of Surgical Management

Considering all of the above, SWL is still believed to be the most commonly used and primary treatment modality for management of uncomplicated kidney stones\textsuperscript{8}. The minimally-invasive nature, ease of performance and low perceived morbidity contribute to the frequent use of this modality\textsuperscript{2}. However, the most important drawback is the need for repeat treatment in a substantial proportion of patients.

URS offers patients a minimally invasive approach with an equal or greater likelihood of achieving stone-free status compared to SWL, but with fewer treatments needed. This comes at the expense of needing a general anesthetic and the possibility of greater post-treatment morbidity.

Lastly, PCNL the most invasive treatment modality is reserved for the largest and most complex renal stones, where the high success rates balances the more significant procedure related morbidity.

2.3.4 Non Surgical Management

Conservative/Expectant

As previously mentioned, many patients with renal or ureteral calculi will not require intervention. In the case of small ($<5\text{mm}$), non-obstructive, asymptomatic renal stones or ureteral stones $\leq 5\text{mm}$ conservative management should be considered.

Patients undergoing conservative management for renal stones require regular follow-up, as based on one study 77\% of asymptomatic renal stones will progress and 26\% of patient will ultimately require surgical intervention\textsuperscript{45}.
For ureteral stones if significant progress or passage of the stone has not occurred within 4 weeks of observation intervention is usually required\textsuperscript{46}.

**Medical Expulsive Therapy**

Medical expulsive therapy (MET) is the use of pharmacologic agents to promote ureteral stone passage by relaxing ureteral smooth muscle. Both $\alpha$-adrenergic blockers and calcium-channel blockers have been shown to increase the likelihood of spontaneous stone passage\textsuperscript{47}. However, a recent meta-analysis found that $\alpha$-adrenergic blockers were superior to the calcium-channel blocker nifedipine and as such may be the preferred agent for MET\textsuperscript{8}. MET is commonly utilized now in patients who undergo conservative/expectant management for ureteric calculi.

### 2.4 Technologic Advances

The management of kidney stone disease has changed dramatically over time with significant new technologic and treatment advances in the past 25 years\textsuperscript{13}, with URS, in particular, being significantly impacted. The technologic advances have been mainly in the fields of fiberotics, lithotripsy and stone removal/retrieval devices and have allowed for more efficient stone fragmentation and removal\textsuperscript{48} with the ureteroscopic approach.

During this same period of continual and rapid advances in technology and technique in the ureteroscopic arena, the progression of SWL technology has remained sluggish. Advancements in SWL have been limited primarily to improvements in treatment technique, optimizing outcomes by increasing stone breakage and reducing tissue injury. Specifically, studies have shown a benefit to a decreased rate of shockwave delivery (60 vs. 120 shocks per minute) for more effective stone fragmentation\textsuperscript{49,50} and
protection of the renal vasculature\textsuperscript{51,52}. Similarly, voltage stepping appears to both improve stone breakage\textsuperscript{53} and reduce tissue injury\textsuperscript{54,55}. However, any benefit these treatment changes might offer has, at least in part, been offset by the fact that the newer second and third generation lithotripters provide inferior fragmentation to the more powerful early electrohydraulic lithotripters\textsuperscript{56}, which are rarely in use.

### 2.4.1 Fiberoptics

Refinements in fiberoptic technology have resulted in progressively smaller and more flexible endoscopes making it both possible and simpler to reach stones in the proximal ureter and all parts of the kidney\textsuperscript{29}. Furthermore the smaller more flexible endoscopes are less traumatic.

One trial completed prior to most of the advances in fiberoptics demonstrated an inability to access the lower pole calyx of the kidney for treatment purposes in 14\% of cases\textsuperscript{57}. Conversely, a contemporary series of URS suggests that as few as 7\% of lower pole calyces cannot be accessed\textsuperscript{58}.

### 2.4.2 Lithotripsy

Improvements in intracorporeal lithotripters, specifically advancements in laser technology have allowed for more efficient and safer stone fragmentation and use of miniaturized equipment\textsuperscript{15}.

The coumarin pulsed-dye laser, was the first widely available laser lithotrite, but was limited by some major drawbacks: stones of certain composition (calcium oxalate monohydrate, cystine) would not fragment well or at all, coumarin dye is a toxic agent
and required cumbersome disposal procedures, and the required eye protection made visualization of the stone and fiber difficult.

Ongoing technologic advancements eventually let to the development of the holmium:YAG laser. The holmium:YAG laser represented a major advance in intracorporeal lithotripsy. This is in light of several important advantages, which make the holmium laser one of the safest, most effective and most versatile intracorporeal lithotripters. Specifically, the holmium laser can transmit energy through a flexible fiber, facilitating intracorporeal lithotripsy throughout the entire collecting system of the kidney. Furthermore, compared to other intracorporeal lithotrites, the holmium laser is safer and more efficient. The holmium laser may be activated at a distance of 0.5 to 1 mm from the ureteral wall, safely without injury. In addition, the holmium laser can fragment stones of all composition and produces significantly smaller fragments as compared to other lithotrites. Lastly, the holmium laser produces a weak shockwave that translates into a lower likelihood of stone retropulsion, further enhancing its efficiency.

2.4.3 Stone Retrieval Devices

Paralleling the significant improvements in fiberoptics and intracorporeal lithotripters have been equally dramatic improvements in ureteroscopic stone removal and retrieval devices. Stone retrieval devices have evolved from helical stainless steel wired baskets to nitinol tipless baskets. The tipless design and the flexibility of nitinol (combination of nickel and titanium) have minimized trauma to the urinary tract while also allowing the capture of stones anywhere in the collecting system. In particular, it was
only with the introduction of nitinol baskets that it became possible to reliably access lower pole renal stones ureteroscopically for fragmentation and removal.

**2.4.4 Outcome of Technological Advances**

As a result of the above technologic advances, in conjunction with improved technical skill over time, URS has been reported to have become more efficacious, associated with less complications and a more commonly used modality than before.

**Efficacy**

The best evidence to support the improved overall efficacy of URS comes from a recent meta-analysis synthesizing data from numerous studies and summarizing the American Urologic Association (AUA) and European Association of Urology (EAU) guidelines for the management of ureteral stones in 2007. This review demonstrates similar stone-free rate for URS as compared to SWL for distal and proximal ureteral stones. The prior meta-analysis supporting the AUA guidelines published in 1997 showed similar efficacy between URS and SWL only for distal ureteral stones. In the 1997 guidelines, SWL was recommended for proximal ureteral stones because of better stone-free rates as compared to URS. Technologic advances and improvements in flexible ureteroscopes have resulted in improved access to the proximal ureter, which in combination with greater technical skill and the introduction of devices to prevent stone migration, have translated into superior stone-free rates with URS (81%) compared to previously (72%). These stone-free rates are now comparable to those achieved with SWL and accordingly the 2007 guidelines recommend SWL or URS as first line treatment for ureteral stones at all levels (distal and proximal).
In addition, this same meta-analysis showed that modern URS is more likely to achieve stone free status after a single procedure as compared to SWL\textsuperscript{8}.

Similarly, a recent Cochrane meta-analysis of 7 RCT’s, demonstrated that the retreatment rate was lower in URS patients compared to SWL\textsuperscript{9}.

\textit{Complications}

As modern ureteroscopes have become smaller and less traumatic with refinements in fiberoptics technology, as safer intracorporeal lithotripters have become widely available (e.g., holmium:YAG laser), and as technical skill with modern equipment has advanced, the number of complications arising from the management of ureteral stones with URS has been reported to be steadily decreasing.

Specifically, over the past 20 years the rate of ureteral perforation or stricture has decreased from 8\% in 1986\textsuperscript{63} to between 0\% and 4.7\% in more recent reports\textsuperscript{10,11,15}. A recent large retrospective review examining 3,938 ureteroscopies from a single institution revealed postoperative complications were very rare, with a ureteral stricture rate of 0.1\%\textsuperscript{11}. Another large retrospective single centre series reviewing 2735 URS between June 1994 and February 2005 demonstrated that 76\% of the complications occurred in the first 5 years of the series\textsuperscript{14}.

Ureteric avulsion, the most catastrophic complication that can occur during URS, has been shown to be now a very rare occurrence with modern URS. Two recent large retrospective reviews reported a rate of 0\% and 0.1\%\textsuperscript{10,11}.

\textit{Increased Utilization}

Several studies have shown an increase in the utilization of URS as compared to SWL\textsuperscript{5,10-12}. These studies have been mainly single centre retrospective series\textsuperscript{10,11} or based
on physician surveys\textsuperscript{12,64}. Two of the largest retrospective series both show a sizable increase in the use of URS, from an average of 299 to 438 URS per year\textsuperscript{11} and 86 to 250 URS per year\textsuperscript{10}.

The lone existing study using population level data is from the United Kingdom (UK), and it also revealed a sizable increase in the number of ureteroscopic procedures being performed, showing a 127% (6,283 to 14,242 cases) increase over ten years\textsuperscript{5}.

Also of note, another recent study demonstrated that providers who more recently completed their residency training were more likely to use URS compared to SWL\textsuperscript{65}.

2.5 Limitations of the current literature with respect to treatment trends

There have been several studies examining treatment trends in the surgical management of kidney stone disease that have demonstrated an increased use of URS. However, these studies have been predominantly based on physician surveys\textsuperscript{12,64} or retrospective series from single centres\textsuperscript{10,11,14}. In either case, these results may not be generalizable or truly reflective of actual practice patterns. The largest retrospective studies were completed at academic centres, which likely have access to more technologically advanced equipment and are more likely to have the most highly trained subspecialists. In fact, one survey study revealed that urologist practicing at academic institutions showed the greatest increase in the use of URS\textsuperscript{12}. This same study showed that the academic urologists had significantly greater access to new technology as compared to non-academic urologist\textsuperscript{12}. This certainly supports the notion of lack of generalizability of these retrospective series. In addition, these large retrospective series do not provide a denominator for the total number of stone procedures being performed.
and so the increased utilization of URS could simply represent an increase in kidney stone surgery rather than a greater proportional use of ureteroscopy.

Although one population-based study from the UK examining treatment utilization trends does exist, the results of this study are hard to interpret based on the limitations of the reported data. All data are reported as a procedure count and not a rate, meaning the increase in the UK population over the 10-year study period is not accounted for. The number of URS procedures is shown to have increased dramatically (127%), however the total number of procedures was also shown to have increased (63%), as was the number of SWL procedures (55%) over the same time period. In addition, the population level data in this study (Hospital Episodes Statistics (HES)) is from patients treated under the publicly funded health care system (National Health Service) and does not include those treated under the private system. Furthermore, the validity of the HES database has been questioned in the literature. A review article assessing many of the studies evaluating the validity of the HES database indicates that local variations in coding practice have inevitably lead to inaccuracies.

Ultimately, none of the existing studies provide sufficient information to accurately quantify the increase in URS utilization.

Furthermore, the studies showing a high success rate and low complication rate with modern URS have largely been completed at high volume centres with technical expertise. However, many centres may lack technologically up to date equipment and technical expertise necessary to achieve these results.

Notwithstanding, that most studies demonstrating high success rates are from high volume, expert centres, and accepting the lower retreatment rates for URS as compared to
SWL\textsuperscript{8,9}, it is still unclear when considering secondary/auxiliary procedures whether URS has an advantage over SWL\textsuperscript{8,9}. In the Cochrane meta-analysis that demonstrated a lower risk for retreatment with URS, it also showed that SWL patients were less likely to need auxiliary treatment (RR 0.43, 95\% CI 0.25 to 0.74) compared to URS. Equally, the weighted mean secondary procedures per patient in the AUA/EAU guidelines meta-analysis appears to be higher for URS versus SWL.

Assessment of treatment outcomes and complications at a population level, in the treatment of kidney stone disease, has not been previously examined. Considering the increasing incidence and prevalence of kidney stone disease and the economic burden associated with its treatment, it is important to accurately describe treatment trends and assess the impact of these trends on patient outcomes. Administrative databases, within the context of the universal healthcare system in Ontario, provide an opportunity to examine this at a population level and address the limitations of the existing research in this area.
Chapter 3 Methods

3.1 Study Design

This is a provincial, population-based, cross-sectional time series study using data derived from administrative databases.

3.2 Study Methodology Overview

This study includes all patients treated for a kidney stone with SWL, URS or PCNL in the province of Ontario over a recent 20-year period (July 1, 1991 - December 31, 2010). Data were derived from physician procedural reimbursement claims, hospital discharge abstracts and ambulatory care visits to emergency rooms. Treatment utilization, as well as the need for repeat/auxiliary treatment and post-treatment morbidity, were examined both for all treatments and separately for each treatment modality.

3.3 Data Sources

All of the data sources utilized in this thesis are listed in Table 3.1. Dates and primary use of each database are also listed. Below, the three main data sources are discussed in more detail.
Table 3.1. Summary of Data Sources

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Use</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIHI-DAD</td>
<td>Cohort demographics and Outcome measurement</td>
<td>• 1993-2010</td>
</tr>
<tr>
<td>OHIP</td>
<td>Cohort identification and demographics and Outcome measurement</td>
<td>• 1991-2010</td>
</tr>
<tr>
<td>NACRS</td>
<td>Outcome measurement</td>
<td>• 2000-2010</td>
</tr>
<tr>
<td>RPDB</td>
<td>Cohort demographics and Risk adjustment</td>
<td>• 1991-2010</td>
</tr>
<tr>
<td>Estimates-Statistics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: CIHI DAD – Canadian Institute for Health Information Discharge Abstract Database; OHIP – Ontario Health Insurance Plan; RPBD – Registered Persons Database.

3.3.1 Ontario Health Insurance Plan data

In the province of Ontario there is a single payer universal health care insurance plan, the Ontario Health Insurance Plan (OHIP). This plan, covers the fees associated with the appropriate health care services provided by physicians, groups, laboratories and out-of-province providers. The OHIP dataset contains all of the claims paid for by OHIP from July 1991 until present. The main data elements in the OHIP dataset include the service provided, associated diagnosis, fee paid, date of service, patient and physician identifiers (encrypted) and physician specialty.

Data for this study included all SWL, URS and PCNL procedures performed in the province of Ontario between July 1, 1991 and December 31, 2010. These procedures were identified using an algorithm of OHIP procedural fee codes from the 2010 OHIP schedule of benefits. Details of the algorithm are discussed below. The algorithm is listed in Table 3.2.
Kidney stone OHIP procedural fee codes have not been specifically validated, however, there is good face validity for OHIP procedural fee codes, as billing claims typically provide complete capture of procedure codes. Several procedures fee codes have been tested for validity. Specifically, comparison of OHIP records and hospital discharge data for women found rates of agreement to be 93% for cholecystectomy and 94% for hysterectomy. In addition, OHIP physician billing claims for breast surgery showed a 98.1% agreement when compared with chart data.

3.3.2 Canadian Institute for Health Information Discharge Abstract Database data

The Canadian Institute for Health Information (CIHI) is an independent, not-for-profit organization that provides essential data and analysis on Canada’s health system and the health of Canadians. CIHI is responsible for building and maintaining 27 pan-Canadian databases that capture information across the continuum of health care services in Canada that subsequently allow for comparisons among jurisdictions. For the purposes of the current study, data from the CIHI Discharge Abstract Database (DAD) and Same Day Surgery (SDS) database were utilized. CIHI-DAD is a national database of all admissions to acute care institutions, and includes all provinces except Quebec and non-Winnipeg Manitoba prior to fiscal 2004.

Data for this study included all acute inpatient records and same day surgery records within 7 days of treatment or hospital discharge for all patients treated with SWL, URS and PCNL between January 1993 and March 2010. Any CIHI-DAD/SDS record following SWL, URS or PCNL was included in our determination of hospital readmission rate, regardless of diagnosis for readmission (i.e., any ICD-9 or ICD-10 code). These records were identified using encrypted health card numbers and treatment
dates for all patients who had undergone a kidney stone treatment (i.e., SWL, URS, PCNL) between January 1993 and March 2010, as previously identified through the OHIP database.

The quality of data in the CIHI-DAD is ensured by extensive data quality control measures. This includes testing of abstracting software before data are submitted, CIHI’s production system edits and correction process, the CIHI education program, client support and special data quality studies. In addition, CIHI’s Data Quality Department evaluates coding accuracy via re-abstraction studies\(^{69-71}\).

### 3.3.3 National Ambulatory Care and Reporting System data

The National Ambulatory Care Reporting System (NACRS) is a data collection tool used to capture information on patient visits to hospitals and community based ambulatory care centres, including outpatient clinics (cancer centre clinics and renal dialysis clinics) and emergency departments. The NACRS dataset contains data on emergency department (ED) visits starting from July 2000.

For the purposes of this study we included all emergency department records within 7 days of treatment or hospital discharge for all patients treated with SWL, URS and PCNL, between July 2000 and March 2010. Any NACRS ED record following SWL, URS or PCNL was included in our determination of post-procedure ED visit rate, regardless of the diagnosis for the ED visit. These records were identified by linking the encrypted health card numbers and treatment dates for all patients who had undergone a kidney stone treatment (i.e., SWL, URS, PCNL) between July 2000 and March 2010, previously identified through the OHIP database, with the NACRS dataset.
The NACRS dataset is also maintained by CIHI and similar to the CIHI-DAD, a re-abstraction study has also been performed on the NACRS dataset confirming its accuracy.\textsuperscript{72}

### 3.4 Inclusion/Exclusion Criteria for the study

The initial study sample included all SWL, URS and PCNL treatments performed in the province of Ontario between July 1991 and December 31, 2010, in patients 18 years of age and older, who were residents of Ontario. Pediatric patients were not included in the study sample, as kidney stone disease is much less prevalent in this population, and is typically secondary to inherited metabolic disorders. Accordingly, the determinants of treatment and surgical options differ in the pediatric population, in addition to different anatomic considerations that influence surgical management. Other indications for URS, such as the evaluation and/or treatment of upper tract urothelial carcinoma and ureteropelvic junction obstruction were not included, since our objective was specifically to evaluate the treatment of kidney stone disease.

Kidney stone treatments were excluded if multiple OHIP procedural fee codes were present and conflicting based on our pre-defined algorithm (Figure 3.1), making it impossible to determine which of the three treatments the patient had undergone. Specifically, treatments with procedural fee codes for both SWL and URS or SWL and PCNL on the same day were excluded. In addition, any treatments for which the encrypted patient health card number (ICES key number) was invalid were excluded, as this would preclude linking patient data across databases and ultimately determining study outcomes.
3.5 Ethics and Confidentiality

This study utilizes information obtained from administrative databases. Data collection and analysis for this thesis only occurred after approval by the Sunnybrook Health Sciences Centre institutional review board and the University of Toronto Office of Research Ethics. All data were uniquely labeled using encrypted health card numbers. No unique identifiers such as patient name, OHIP number, postal code or address were recorded.

3.6 Cohort Identification

After ethics approval, we identified all SWL, URS and PCNL kidney stone procedures performed in the province of Ontario between July 1, 1991 and December 31, 2010 from the OHIP database using procedural fee codes from the 2010 OHIP schedule of benefits. The existence and definition of these fee codes has remained stable over the course of our study period. The algorithm of fee codes utilized is listed in Table 3.2.

Table 3.2. Algorithms of OHIP Procedural Fee Codes

<table>
<thead>
<tr>
<th>Procedure</th>
<th>OHIP Procedural Fee Code(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWL</td>
<td>Z630</td>
</tr>
<tr>
<td>URS</td>
<td>Z628 + E760 or E761 or Z627</td>
</tr>
<tr>
<td>PCNL</td>
<td>Z624 + Z627</td>
</tr>
</tbody>
</table>

Abbreviations: SWL- Shockwave lithotripsy; URS- Ureteroscopy; PCNL- Percutaneous Nephrolithotomy; OHIP- Ontario Health Insurance Plan.

The fee code for SWL (Z630) is very specific for the treatment of kidney stones, as the procedure is otherwise only performed for pancreatic stones, which is done very rarely.
URS, which is denoted by the fee code Z628, may be performed for diagnostic and therapeutic purposes in the evaluation and treatment of urothelial carcinoma, hematuria, ureteropelvic junction obstruction and ureteral stricture disease, in addition to renal and ureteral calculi. As such, the URS fee code (Z628) was combined with the fee code for either removal of ureteric (E760) or renal calculi (Z627) or intracorporeal lithotripsy (E761) to ensure that we were specifically identifying ureteroscopies for kidney stone treatment.

PCNL is not defined by a single fee code in the OHIP schedule of benefits. Accordingly the codes for dilation of percutaneous tract (Z624) and removal of renal calculi (Z627), two essential components of the procedure were combined to identify this procedure.

**Multiple/Conflicting Procedural Codes**

To resolve potential procedures where multiple fee codes exist denoting more than one of the three predefined kidney stone procedures, based on the above algorithm (Table 3.2), a multiple OHIP procedural fee code algorithm was also devised (Figure 3.1). Although it is possible SWL and URS or SWL and PCNL might be performed on the same patient on the same day, this would not be considered the usual practice, but instead rather unorthodox. In fact the combination of SWL and PCNL might in fact represent errors in physician claim billing. Accordingly, such combined procedures were excluded.

Alternatively, antegrade URS is not uncommonly performed during PCNL procedures, when large proximal ureteral stones or fragments exist. As such the existence of codes for both PCNL and URS were simply interpreted as PCNL.
Abbreviations: SWL- Shockwave lithotripsy; URS- Ureteroscopy; PCNL- Percutaneous Nephrolithotomy; OHIP- Ontario Health Insurance Plan.

3.7 Demographic Information

Demographic information on all patients undergoing kidney stone treatment during the 20-year study period was collected. Demographics were summarized both for the entire cohort of patients and by treatment modality. The specific demographics included were age, gender, socioeconomic status (for area of residence) and region of residence (rural vs. urban). Demographic information was obtained from the RPDB (age, gender, region via postal code), Canadian Census (Income Quintile for area of residence) and OHIP database. In addition, an index of comorbidity (Ambulatory Care Group (ACG) measure) was included for all patients, which was obtained from CIHI-DAD.

Seeing that a large number of patients underwent more than one kidney stone treatment, demographic information at the time of first treatment was utilized. Age was reported as a mean and range, while gender, region of residence and comorbidity measures were reported as proportions. Socioeconomic status was defined by income quintiles and subsequently reported as a proportion.
To summarize the incidence of multiple kidney stone procedures per patient the frequency counts for the number of patients receiving multiple treatments was reported. Lastly, both the crude rate and population-standardized rate of total number of kidney stone procedures per year were reported from 1992-2009. The population-standardized rate was directly standardized for age and gender to the population of Ontario for the year 2000. The rate was standardized to age and gender to account for possible changes in the demographics of the Ontario population over time that might have influenced the incidence and prevalence of stone disease and subsequently kidney stone surgery rates. In particular, considering kidney stone disease is more common in males\textsuperscript{7,22,23}, the rate was standardized to gender. Similarly, because kidney stone disease is rare before the age of 20 and rises to reach a peak incidence in patients 40-60 years old and then declines at age 65\textsuperscript{6,22}, the rate was standardized based on three age strata (18-39, 40-64 and >64). Finer age strata were not used, as the goal was to ensure that the population most at risk for stone disease had not changed dramatically over the study period, in the province of Ontario.

3.8 Outcome Measures

3.8.1 Treatment Utilization

The first principal outcome of this study was trends in treatment utilization over time, specifically, the utilization of SWL, URS and PCNL in the treatment of kidney stones. Two measures of treatment utilization were evaluated. The first was the proportion of all kidney stone treatments represented by each modality for every 3-month block over the study period. The second measure of treatment utilization was a
population adjusted utilization rate for each modality for every year over the study period. The population-adjusted rate was directly standardized for age and gender to the population of Ontario for the year 2000. Age was standardized based on three strata (18-39, 40-64 and >64). Age and gender standardized rates were examined for the same reasons detailed above.

The OHIP dataset was used, as described above, for determining treatment modality utilization. Ontario Population Estimates data from Statistics Canada was used for the calculation of the population-adjusted standardized rate.

The study time frame for this outcome was July 1, 1991 to December 31, 2010. This represents the maximal time limits for OHIP data at the time of data acquisition. This time frame was chosen for this outcome as no look back period prior to treatment or observation period post-treatment was necessary. However, it should be noted that for the population adjusted utilization rate, rates are reported from 1992 to 2009. Seeing that we only had a half-year worth of data for 1991, the standardized rate is reported starting in 1992. Furthermore, Ontario population data were only available up to 2009 at the time of data analysis and as such the population adjusted utilization rates could only reported up to and including 2009.

3.8.2 Need for Ancillary Treatment

Ancillary treatment was defined as a second kidney stone treatment, either of the same modality (i.e., repeat procedure) or a different modality (i.e., auxiliary procedure), occurring within 90 days of an index stone treatment. An index stone treatment was considered the initial treatment for any particular stone and was defined as any kidney stone procedure without another stone procedure occurring within 90 days prior to it. The
measure of need for ancillary treatment was the proportion of all index stone procedures requiring ancillary treatment for every 3-month block over the study period. This was calculated both for all modalities combined, as well as for each modality separately.

Again, the OHIP dataset was used for determining the need for ancillary treatment.

The study time frame for the ancillary treatment outcome was defined as January 1, 1992 to September 30, 2010. The first 6 months of kidney stone procedures (July 1 - December 31, 1991) were excluded to allow for an adequate look back period to make it possible to define index versus ancillary procedures at the start of the study period. Since the OHIP database starts July 1, 1991, we would not have had a look back period if our study time frame started on this day. Similarly, we require an observation period post index treatment to determine if an ancillary procedure was necessary. As such, the study period, for this outcome, ends on September 30, 2010 to allow a 90-day window for observation of ancillary treatments, prior to the end of the OHIP dataset (December 31, 2010).

For this outcome sensitivity analysis was also performed. In this sensitivity analysis the time frame definition for ancillary treatment was changed to 60, 120 and 180 days, to see if this would have an effect on the outcome of need for ancillary treatment over time.

The study time frame for the sensitivity analysis was adjusted accordingly, based on the time frame definition for ancillary treatment, to allow for an adequate observation period following the end of the study period. For example, when the time frame definition for ancillary treatment was extended to 180 days, the study time frame ended
June 30, 2010, to allow 6 months post-treatment to observe if an ancillary treatment was required.

### 3.8.3 Morbidity

The third principal outcome of this study was morbidity following treatment. We examined two different end points to assess morbidity post-procedure; hospital readmission and ED visit.

**Hospital Readmission**

Hospital readmission post-treatment was defined as readmission to hospital for any cause within 7 days of hospital discharge following kidney stone treatment, or if the date of hospital discharge could not be determined, then within 7 days of the date of treatment. The measure of hospital readmission was the proportion of all stone treatments that required hospital readmission for every 3-month block over the study period. This was calculated both for all modalities combined, as well as for each modality separately. All hospital readmissions were included in this outcome measure, as opposed to simply examining readmissions secondary to procedure specific causes (e.g., bleeding, urospesis), for two reasons. First, the objective in evaluating morbidity from stone treatment was to capture readmission post-procedure not only for procedure specific complications, but also from all other causes (e.g. myocardial infarction, congestive heart failure, pneumonia, deep vein thrombosis). Second, urologic specific diagnostic codes have not been previously validated, which might subsequently have affected the accuracy of our findings.
The study time frame for the hospital readmission outcome was defined as January 1, 1993 to March 31, 2010. The CIHI-DAD dataset begins in 1988, but for the purposes of our study a full complement of separations/records was available beginning in 1993. At the time of our data acquisition the CIHI-DAD dataset contained complete records until beyond the end of the first quarter of 2010. To allow for a the necessary 7 day observation period to look for hospital readmission post-treatment, March 31, 2010 was chosen as the time frame end date for this outcome.

Hospital readmission rate was determined using the CIHI-DAD dataset by linking with the OHIP dataset, listing all kidney stone procedures.

**Emergency Department Visits**

Similar to hospital readmission, ED visit post-treatment was defined as any ED visit occurring within 7 days following hospital discharge for a kidney stone procedure, or if the date of hospital discharge could not be determined, then within 7 days of the date of treatment. The measure of ED visits post-treatment was the proportion of all stone treatments that required an ED visit for every 3-month block over the study period. This was calculated both for all modalities combined, as well as for each modality separately. Similar to hospital readmission and for the same reasons, this outcome measure included ED visits post-procedure for any cause, not just urologic specific causes.

The study time frame for the ED visit outcome was defined as July 1, 2000 to March 31, 2010. The NACRS dataset begins in the fiscal year 2000 with a full complement of separations beginning in July 2000. At the time of our data acquisition the NACRS dataset contained complete records until beyond the end of the first quarter of 2010. To allow for the necessary 7-day observation period to look for ED visit post-
treatment/discharge, March 31, 2010 was chosen as the time frame end date for this outcome.

The ED visit rate post-treatment was determined using the NACRS dataset by linking with the OHIP dataset, listing all kidney stone procedures.

### 3.9 Statistical Analysis

#### 3.9.1 Demographic Summary and Analysis

In addition to summarizing the demographics of all patients treated over the 20-year study period, selected demographical information was also reported for every year of the study period to allow for graphical assessment of changes in the demographics of patients undergoing treatment for kidney stones over time. Age, gender and socioeconomic status were the selected demographic variables. Age was divided into three strata (18-39, 40-64, >64) and each strata was reported as both a proportion of all kidney stone treatments per year and a gender standardized rate per year. As outlined previously, the rate was standardized for gender to the Ontario population for the year 2000, in light of the greater prevalence of stone disease in males versus females. Similarly, gender was reported as both a proportion of all kidney stone treatments per year and an age standardized rate per year. The rate was standardized for age to the Ontario population for the year 2000, in three age strata (18-39, 40-64, >64). As before, the rate was standardized for age to account for possible changes in the age distribution of the population of Ontario over time, considering kidney stone disease peaks in incidence from 40-64 years old. Socioeconomic status was defined by income.
quintiles and each quintile reported as a proportion of all kidney stone treatments per year.

**3.9.2 Time Series Analysis**

To assess for significant trends over time with each of the three respective principal outcomes, time series analysis was employed. Specifically, time series analysis involving exponential smoothing models and autoregressive integrated moving average (ARIMA) models were used to assess for changes over time.

All time series models were thoroughly evaluated to ensure they satisfied the necessary assumptions. Specifically, stationarity was assessed using the autocorrelation function and the augmented Dickey–Fuller test. Model parameter appropriateness and seasonality were assessed with the autocorrelation, partial autocorrelation and inverse autocorrelation functions. Lastly, the presence of white noise was assessed by examining the autocorrelations at various lags using the Ljung–Box $\chi^2$ statistic. The Schwarz Bayesian Information Criterion was used to discriminate between exponential smoothing and ARIMA models, to identify the model of best fit. A $p < 0.05$ was used to indicate a significant trend over time.

All statistical analysis was performed using SAS 9.2 software (SAS Institute Inc., Cary, N.C.).

All time series models were displayed graphically such that all observed data points were plotted as grey point without adjoining lines and all predicted data values, based on the time series model, were plotted in colour with adjoining lines. All reported percentages and rates for each principal outcome detailed in the results section represent the model-projected values, as opposed to the observed values. The model projected
values were reported because the determination of significant trends over time were based on the time series model of best-fit generated for each outcome. In addition, considering that the observed data occasionally showed large variability in rates, even from one 3-month block to the next, the smoothed curve of the time series model provided a more representative estimate of the change seen over time.
Chapter 4 Results

4.1 Descriptive Statistics and Demographics Summary

4.1.1. Descriptive Statistics

We identified 194,818 kidney stone procedures performed in 116,131 patients, prior to exclusions, between July 1, 1991 and December 31, 2010. Thirty-seven procedures occurring in 16 patients were excluded because of conflicting OHIP procedural codes, based on the pre-defined algorithm (Figure 3.1). The remaining 194,781 procedures occurring in 116,115 patients represented the study cohort (Ontario Kidney Stone Cohort (OKSC)) for our cross-sectional time series analysis. The breakdown of the procedures occurring in the OKSC is listed in Table 4.1. A summary of the demographic characteristics of the 116,115 patients comprising the OKSC can be found in Table 4.2. Additionally, a summary of the demographics of patients treated by each modality is reported in Table 4.3. A small number of patients from the cohort were missing certain demographical information (Income quintile- 686, Region of Residence- 212).

The frequency counts of number of patients receiving either single or multiple kidney stone procedures over the study period are displayed graphically in Figure 4.1. The majority (66%) of patients underwent a single kidney stone treatment over the study period. Nineteen percent underwent two procedures and 7.6% underwent three procedures over the study period. Only 7.4 % of patients underwent more than three procedures, with the greatest number of procedures in one patient being 52.

Over the study period, the rate of kidney stone procedures being performed per year increased steadily. Both the crude and population standardized rates are displayed in
Figure 4.2. Considering the crude rate, kidney stone procedures have increased from 85/100,000 to 126/100,000. Similarly, the standardized rate of kidney stone procedures has increased from 90/100,000 to 120/100,000.

Table 4.1. Breakdown of Kidney Stone Procedures Occurring in the OKSC

<table>
<thead>
<tr>
<th>Procedure</th>
<th>N=194,781</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWL</td>
<td>96,807</td>
</tr>
<tr>
<td>URS</td>
<td>83,923</td>
</tr>
<tr>
<td>PCNL</td>
<td>14,051</td>
</tr>
</tbody>
</table>

*Abbreviations: OKSC- Ontario Kidney Stone Cohort; SWL- Shockwave lithotripsy; URS- Ureteroscopy; PCNL- Percutaneous Nephrolithotomy.*

Table 4.2. Summary of OKSC Demographics

<table>
<thead>
<tr>
<th>Demographics</th>
<th>N= 116,115&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age- Mean (Range)</strong></td>
<td>50.8 (18-101)</td>
</tr>
<tr>
<td><strong>Gender (%)</strong></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>73,411 (63.22)</td>
</tr>
<tr>
<td>F</td>
<td>42,704 (36.78)</td>
</tr>
<tr>
<td><strong>Income Quintile (%)&lt;sup&gt;b&lt;/sup&gt;</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>22,854 (19.8)</td>
</tr>
<tr>
<td>2</td>
<td>23,550 (20.4)</td>
</tr>
<tr>
<td>3</td>
<td>23,036 (19.96)</td>
</tr>
<tr>
<td>4</td>
<td>23,425 (20.29)</td>
</tr>
<tr>
<td>5</td>
<td>22,564 (19.55)</td>
</tr>
<tr>
<td><strong>Region (%)&lt;sup&gt;b&lt;/sup&gt;</strong></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>101,465 (87.54)</td>
</tr>
<tr>
<td>Rural</td>
<td>14,439 (12.46)</td>
</tr>
<tr>
<td><strong>ACG Chronic Medical Condition-Stable (%)</strong></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>23,705 (20.42)</td>
</tr>
<tr>
<td>No</td>
<td>92,410 (79.58)</td>
</tr>
<tr>
<td><strong>ACG Chronic Medical Condition-Unstable (%)</strong></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>9482 (8.17)</td>
</tr>
<tr>
<td>No</td>
<td>106633 (91.83)</td>
</tr>
</tbody>
</table>

*Abbreviations: OKSC- Ontario Kidney Stone Cohort; ACG- Ambulatory Care Groups  
<sup>a</sup>The numbers do not always sum to group totals due to missing information for some variables.  
<sup>b</sup>Excludes 686 and 212 patients with missing information for income quintile and region of residence respectively.
Table 4.3. Summary of OKSC demographics by treatment modality

<table>
<thead>
<tr>
<th>Demographics</th>
<th>SWL (N=54,071)</th>
<th>URS (N=54,200)</th>
<th>PCNL (N=7,844)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age- Mean (Range)</td>
<td>50.4 (18-96)</td>
<td>50.8 (18-101)</td>
<td>54.6 (18-94)</td>
</tr>
<tr>
<td>Gender (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>34,912 (64.57)</td>
<td>34,164 (63.03)</td>
<td>4,335 (55.27)</td>
</tr>
<tr>
<td>F</td>
<td>19,159 (35.43)</td>
<td>20,036 (36.97)</td>
<td>3,509 (44.73)</td>
</tr>
<tr>
<td>Income Quintile (%)&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>10,340 (19.26)</td>
<td>10,649 (19.74)</td>
<td>1,865 (23.93)</td>
</tr>
<tr>
<td>2</td>
<td>10,638 (19.81)</td>
<td>11,205 (20.77)</td>
<td>1,707 (21.91)</td>
</tr>
<tr>
<td>3</td>
<td>10,502 (19.56)</td>
<td>11,014 (20.42)</td>
<td>1,520 (19.51)</td>
</tr>
<tr>
<td>4</td>
<td>11,061 (20.6)</td>
<td>10,958 (20.32)</td>
<td>1,406 (18.04)</td>
</tr>
<tr>
<td>5</td>
<td>11,159 (20.78)</td>
<td>10,111 (18.75)</td>
<td>1,294 (16.61)</td>
</tr>
<tr>
<td>Region (%)&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>47,871 (88.73)</td>
<td>46,742 (86.37)</td>
<td>6,852 (87.48)</td>
</tr>
<tr>
<td>Rural</td>
<td>6,080 (11.27)</td>
<td>7,378 (13.63)</td>
<td>981 (12.52)</td>
</tr>
<tr>
<td>ACG Chronic Medical Condition-Stable (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>9,180 (16.98)</td>
<td>12,690 (23.41)</td>
<td>1,835 (23.39)</td>
</tr>
<tr>
<td>No</td>
<td>44,891 (83.02)</td>
<td>41,510 (76.59)</td>
<td>6,009 (76.61)</td>
</tr>
<tr>
<td>ACG Chronic Medical Condition-Unstable (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>3,976 (7.35)</td>
<td>4,596 (8.48)</td>
<td>910 (11.6)</td>
</tr>
<tr>
<td>No</td>
<td>50,095 (92.65)</td>
<td>49,606 (91.52)</td>
<td>6,934 (88.4)</td>
</tr>
</tbody>
</table>

Abbreviations: SWL- Shockwave lithotripsy; URS- Ureteroscopy; PCNL- Percutaneous Nephrolithotomy; OKSC- Ontario Kidney Stone Cohort; ACG- Ambulatory Care Groups

<sup>a</sup>The numbers do not always sum to group totals due to missing information for some variables.

<sup>b</sup>Excludes 686 and 212 patients with missing information for income quintile and region of residence respectively.
Figure 4.1. Frequency Distribution of Number of Procedures per Patient in the OKSC

Abbreviations: OKSC- Ontario Kidney Stone Cohort.
4.1.2 Demographics over time

The overall ratio of male to females in the entire cohort was approximately 1.7:1, however, there were some interesting changes in the gender composition of patients being treated over time. Specifically, the proportions of females treated increased over time from 32.9% to 40.1%, with a reciprocal decrease in the proportion of males (Figure 4.3A). Alternatively, looking at rates of treatment, we see that the rate of females treated increased from 40/100,000 to 53/100,000, while the rate of men treated remained stable over time, notwithstanding some fluctuations, at approximately 82/100,000 (Figure 4.3B).
Similar to gender, changes were also observed in the relative proportions and rates of patients within each of the three defined age strata being treated over time. Most notably both the proportion (18.6%-23.2%) and rate (67.3/100,000 -88.8/100,000) of patients greater than 64 years old being treated increased over time (Figure 4.4).

Conversely, unlike gender and age, there has been no shift in the distribution of patients treated for kidney stones across income quintiles over time (Figure 4.5). Approximately 20% of patients fall into each of the income quintiles in each year of the study period.

**Figure 4.3A. Percent of Kidney Stone Treatments in Males vs. Females Over Time in the OKSC**

**Abbreviations:** OKSC- Ontario Kidney Stone Cohort
Figure 4.3B. Age Standardized Rates of Kidney Stone Treatments in Males vs. Females Over Time in the OKSC

Abbreviations: OKSC- Ontario Kidney Stone Cohort
*Age strata directly standardized rate to the population of Ontario for the year 2000.
Figure 4.4A. Percent of Kidney Stone Treatments by Age Strata Over Time in the OKSC

Abbreviations: OKSC- Ontario Kidney Stone Cohort
Figure 4.4B. Gender Standardized Rates of Kidney Stone Treatments by Age Strata Over Time in the OKSC

Abbreviations: OKSC- Ontario Kidney Stone Cohort
*Gender directly standardized rate to the population of Ontario for the year 2000.
4.2 Treatment Utilization Trends

4.2.1 Proportional Time Series

Time series analysis demonstrated that the use of SWL has decreased significantly from July 1991 to December 2010 (68.77% -33.36%, p<0.0001) (Figure 4.6), while the use of URS has increased significantly (23.69% to 59.98%, p<0.0001) (Figure 4.7) over this same time period. Meanwhile the utilization of PCNL remained stable over time ((7.18% to 7.06%, p=0.97) (Figure 4.8). By the end of 2004 URS had become the most widely utilized procedure (Figure 4.9).
Figure 4.6. Percent Utilization of SWL in the Treatment of Kidney Stone Disease in the OKSC

Abbreviations: SWL- Shockwave lithotripsy; OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

a Time series analysis with Winters Multiplicative exponential smoothing demonstrates a significant decreasing trend over time in the utilization of SWL (68.77% -33.36%).
Figure 4.7. Percent Utilization of URS in the Treatment of Kidney Stone Disease in the OKSC

Abbreviations: URS- Ureteroscopy; OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

\(^a\) Time series analysis with Winters Additive exponential smoothing demonstrates a significant increasing trend over time in the utilization of URS (23.69% - 59.98%).
Abbreviations: PCNL- Percutaneous Nephrolithotomy; OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

\(^a\) Time series analysis with Winters Additive exponential smoothing demonstrates no significant trend over time in the utilization of PCNL (7.18\% - 7.06\%).
Figure 4.9. Percent Treatment Utilization of All Modalities in the Management of Kidney Stone Disease in the OKSC

Abbreviations: SWL- Shockwave lithotripsy; URS- Ureteroscopy; PCNL- Percutaneous Nephrolithotomy; OKSC- Ontario Kidney Stone Cohort.
*Observed data points plotted as grey point without adjoining lines
**Predicted data points based on the time series models plotted in colour with adjoining lines.

4.2.2 Population Standardized Time Series

Examining treatment utilization by population standardized rates over time, revealed similar trends to that of percent utilization. Specifically, time series analysis demonstrated a significant decrease in the utilization rate of SWL (64.5 to 45.2 per 100,000, p<0.0001), with a corresponding significant increase the utilization rate of URS (21.2 to 67.2 per 100,000, p<0.0001) (Figure 4.10). The rate of PCNL use remained relatively static over time (7.1 to 8.5 per 100,000, p=0.996) (Figure 4.10).
Figure 4.10. Population Standardized Treatment Utilization Rates in the Management of Kidney Stone Disease in the OKSC

Abbreviations: SWL- Shockwave lithotripsy; URS- Ureteroscopy; PCNL- Percutaneous Nephrolithotomy; OKSC- Ontario Kidney Stone Cohort.

§Observed data points plotted as grey point without adjoining lines.

*SWL predicted data points based on time series analysis with ARIMA, which demonstrates a significant decreasing trend over time in SWL utilization (64.5-45.2/100,000).

**URS predicted data points based on time series analysis with ARIMA, which demonstrates a significant increasing trend over time in URS utilization (21.3-67.2/100,000).

***PCNL predicted data points based on time series analysis with Linear (Holt) exponential smoothing, which demonstrates no significant trend over time in PCNL utilization.

4.3 Need for Ancillary Treatment Trends

Assuming the 90-day definition for ancillary treatment, there were 149,482 index treatments and 38,368 ancillary treatments over the entire duration of the study period.

This is after exclusion of 3,542 procedures (2,793 index and 749 ancillary procedures) as part of the look back window and 3,389 procedures (2834 index and 555 ancillary
procedures) as part of the observation period, as described in the method section. Table 4.3 summarizes the breakdown of the index and ancillary treatments by modality.

Considering all index procedures over the duration of the study period, 27,963 (18.7%) index procedures required an ancillary procedure. The breakdown of index procedures requiring an ancillary treatment are also listed in Table 4.3.

Table 4.3. Summary of Index and Ancillary Procedures by modality

<table>
<thead>
<tr>
<th>Index procedures(^a)</th>
<th>149,482</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWL</td>
<td>70,267 (47%)</td>
</tr>
<tr>
<td>URS</td>
<td>67,974 (45.5%)</td>
</tr>
<tr>
<td>PCNL</td>
<td>11,241 (7.5%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ancillary procedures(^b)</th>
<th>38,368</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWL</td>
<td>23,015 (60%)</td>
</tr>
<tr>
<td>URS</td>
<td>13,066 (34%)</td>
</tr>
<tr>
<td>PCNL</td>
<td>2,287 (6%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Index procedure requiring ancillary procedures</th>
<th>27,963</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWL</td>
<td>17,915 (64.1%)</td>
</tr>
<tr>
<td>URS</td>
<td>8,424 (30.1%)</td>
</tr>
<tr>
<td>PCNL</td>
<td>1,624 (5.8%)</td>
</tr>
</tbody>
</table>

**Abbreviations:** SWL- Shockwave lithotripsy; URS- Ureteroscopy; PCNL- Percutaneous Nephrolithotomy

\(^a\)Index stone procedure was defined as any kidney stone procedure without another stone procedure occurring within 90 days prior to it.

\(^b\)Ancillary stone procedures were defined as those occurring within 90 days following another stone procedure.

### 4.3.1 90-day Ancillary Treatment Window

Time series analysis demonstrated a significant reduction in the need for ancillary treatment over time (22.12% to 16.01%, \(p<0.0001\)) when considering all treatment modalities (Figure 4.11). Graphically, most of the decreasing trend can be seen after 2004, when URS became the predominant treatment modality. Examining the need for ancillary treatment when subdivided by modality, we see that the need for ancillary
treatment is consistently lower with URS, as compared to SWL and PCNL (Figure 4.12A, B & E).

Furthermore, when evaluating the need for ancillary treatment by modality, a significant trend over time was seen for both URS and PCNL. (Figure 4.12B & E). The slight, but significant decreasing trend for URS (13.00% to 10.80%, p<0.0001) is demonstrated graphically mainly after 2004 (Figure 4.12B). This is further illustrated with separate time series analysis of ancillary treatment for URS prior to 2004 and from 2004 onwards (Figure 4.12C & D). A significant decreasing trend is demonstrated only from 2004 to 2010 (Figure 4.12D). For PCNL, a significant decreasing trend (19.04% to 10.85%, p<0.0001) is demonstrated over the course of the study period (Figure 4.12E).
Figure 4.11. Percentage of Kidney Stone Treatments Requiring Ancillary Treatment (90 day) in the OKSC

Abbreviations: OKSC- Ontario Kidney Stone Cohort.

*a Predicted data points based on the time series model

a Time series analysis with Winters Additive exponential smoothing indicates a significant decreasing trend over time in the need for ancillary treatment (22.12% - 16.01%)
Figure 4.12A. Percentage of SWL Treatments Requiring Ancillary Treatment (90 day) in the OKSC

Abbreviations: SWL- Shockwave Lithotripsy; OKSC- Ontario Kidney Stone Cohort.
*Predicted data points based on the time series model.
\(^a\) Time series analysis with ARIMA demonstrates no significant trend over time in the need for ancillary treatment with SWL.
Figure 4.12B. Percentage of URS Treatments Requiring Ancillary Treatment (90 day) in the OKSC

Abbreviations: URS- Ureteroscopy; OKSC- Ontario Kidney Stone Cohort.
*Predicted data points based on the time series model.

a Time series analysis with Double (Brown) exponential smoothing demonstrates a significant decreasing trend over time in the need for ancillary treatment with URS (13.00% -10.80%)
Figure 4.12C. Percentage of URS Treatments Requiring Ancillary Treatment (90 day) in the OKSC from January 1992- December 2003

Abbreviations: URS- Ureteroscopy; OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

a Time series analysis with Simple exponential smoothing demonstrates no significant trend over time in the need for ancillary treatment with URS.
Figure 4.12D. Percentage of URS Treatments Requiring Ancillary Treatment (90 day) in the OKSC from January 2004- September 2010

Abbreviations: URS- Ureteroscopy; OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

aTime series analysis with ARIMA demonstrates a significant decreasing trend over time in the need for ancillary treatment with URS (13.42% -10.40%)
Figure 4.12E. Percentage of PCNL Treatments Requiring Ancillary Treatment (90 day) in the OKSC

Abbreviations: PCNL- Percutaneous Nephrolithotomy; OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

a Time series analysis with ARIMA demonstrates a significant decreasing trend over time in the need for ancillary treatment with PCNL (19.04% -10.85%)

4.3.2 Sensitivity Analysis

When the definition of ancillary treatment was redefined changing the time frame from 90 days down to 60 days, a significant decreasing trend over time for ancillary treatment rate across all treatment modalities was still seen (19.30% to 13.29%, p=0.02) (Figure 4.13).

Similarly, when the definition of ancillary treatment was redefined, increasing the time frame from 90 days to both 120 days and then 180 days, the results remained consistent. There was a significant trend over time for a decrease in the need for ancillary treatment.
treatment in both the case of the 120-day definition (23.14% to 18.28%, p<0.0001) (Figure 4.14) and the 180-day definition (25.13% to 20.23%, p<0.0001) (Figure 4.15).

As such, the sensitivity analysis demonstrates that whether the time frame definition for ancillary treatment is as short as 60 days or as long as 180 days a similar significant trend for a decrease in need for ancillary treatment is observed over time.

Figure 4.13. Percentage of Kidney Stone Treatments Requiring Ancillary Treatment (60 day) in the OKSC

Abbreviations: OKSC- Ontario Kidney Stone Cohort.
*Predicted data points based on the time series model.
^Time series analysis with Winters Additive exponential smoothing demonstrates a significant decreasing trend over time in the need for ancillary treatment (19.30% - 13.29%).
Figure 4.14. Percentage of Kidney Stone Treatments Requiring Ancillary Treatment (120 day) in the OKSC

Abbreviations: OKSC- Ontario Kidney Stone Cohort.
*Predicted data points based on the time series model.
\(^a\) Time series analysis with Log linear (Holt) exponential smoothing demonstrates a significant decreasing trend over time in the need for ancillary treatment (23.14\% - 18.28\%).
Figure 4.15. Percentage of Kidney Stone Treatments Requiring Ancillary Treatment (180 day) in the OKSC

**Abbreviations:** OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

a Time series analysis with Log linear (Holt) exponential smoothing demonstrates a significant decreasing trend over time in the need for ancillary treatment (25.13% - 20.23%).

### 4.4 Morbidity Trends

#### 4.4.1 Hospital Readmissions

When examining all treatment modalities, time series analysis demonstrated a significant increase in the proportion of treatments requiring hospital readmission within 7 days. The proportion increased from 8.01% to 10.85% (p<0.0001) between January 1993 and March 2010, with most of the increase seen following 2004 (Figure 4.16A). The timing of the increasing trend was confirmed with separate time series analysis of
hospital readmission prior to 2004 and after 2004 (Figure 4.16B & C). A significant increasing trend was seen only after 2004 (8.75%-11.18%, p<0.0001) (Figure 4.16C).

Hospital readmission rate subdivided by treatment modality shows a consistently higher proportion of patients are readmitted following URS as compared to SWL, for each year of the study period (Figure 4.17A & B). Of the three treatment modalities only PCNL demonstrated a significant trend over time for hospital readmission rate. This was an increasing trend with hospital readmission rising from 7.11% to 12.45% (p<0.0001) (Figure 4.17C).

**Figure 4.16A. Percentage of Kidney Stone Procedures Requiring Hospital Readmission within 7 Days of Discharge in the OKSC**

![Graph showing percentage of kidney stone procedures requiring hospital readmission within 7 days of discharge in the OKSC.](image)

**Abbreviations:** OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

a Time series analysis with Log Linear (Holt) exponential smoothing demonstrates a significant increasing trend over time in hospital readmission post-procedure (8.01%-10.85%).
Figure 4.16B. Percentage of Kidney Stone Procedures Requiring Hospital Readmission within 7 Days of Discharge in the OKSC from January 1993-December 2003

Abbreviations: OKSC - Ontario Kidney Stone Cohort.
*Predicted data points based on the time series model.
\(^a\) Time series analysis with ARIMA model demonstrates no significant trend over time in hospital readmission post-procedure.
Figure 4.16C. Percentage of Kidney Stone Procedures Requiring Hospital Readmission within 7 Days of Discharge in the OKSC from January 2004-March 2010

Abbreviations: OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

a Time series analysis with ARIMA model demonstrates a significant trend over time in hospital readmission post-procedure (8.75%-11.18%).
Figure 4.17A. Percentage of SWL Treatments Requiring Hospital Readmission within 7 Days of Discharge in the OKSC

Abbreviations: SWL- Shockwave lithotripsy; OKSC- Ontario Kidney Stone Cohort.
*Predicted data points based on the time series model.
\(^{a}\) Time series analysis with ARIMA demonstrates no significant trend over time in hospital readmission post-SWL.
Figure 4.17B. Percentage of URS Treatments Requiring Hospital Readmission within 7 Days of Discharge in the OKSC

Abbreviations: URS- Ureteroscopy; OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

\( p=0.46^a \)

\(^a\) Time series analysis with ARIMA demonstrates no significant trend over time in hospital readmission following URS.
**Figure 4.17C. Percentage of PCNL Treatments Requiring Hospital Readmission within 7 Days of Discharge in the OKSC**

![Graph showing the percentage of PCNL treatments requiring hospital readmission within 7 days of discharge, with a trend line indicating a significant increasing trend over time, and a p-value of <0.0001.]

**Abbreviations:** PCNL - Percutaneous Nephrolithotomy; OKSC - Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

\(^a\)Time series analysis with ARIMA demonstrates a significant increasing trend over time in hospital readmission post-PCNL (7.11% -12.45%).

### 4.4.2 Emergency Department Visits

Time series analysis of ED visits within 7 days of treatment or discharge, for all treatment modalities, demonstrated a significant increasing trend. Specifically, the proportion of ED visits has increased from 7.58% to 9.95% (p=0.0024) between July 2000 and March 2010 (Figure 4.18).

Similar to hospital readmission trends over time, when subdivided by modality a consistently higher proportion of patients return to the ED after URS as compared to SWL, for each year of the study period (Figure 4.19A & B). Time series analysis
demonstrated a significant increasing trend in the proportion of ED visits over time for URS (10.05% to 11.92%, p=0.0046) (Figure 4.19B). Conversely, there was no significant trend over time in ED visit rate following either SWL (p=0.061) (Figure 4.19A) or PCNL (p=0.28) (Figure 4.19C).

**Figure 4.18. Percentage of Kidney Stone Treatments Requiring an ED Visit within 7 Days of Hospital Discharge in the OKSC**

**Abbreviations:** ED- Emergency Department; OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

aTime series analysis with Winters Additive exponential smoothing demonstrates a significant increasing trend over time in ED visits post-procedure (7.58% -9.95%).
Figure 4.19A. Percentage of SWL Treatments Requiring an ED Visit within 7 Days of Hospital Discharge in the OKSC

**Abbreviations:** SWL - Shockwave lithotripsy; ED - Emergency Department; OKSC - Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

Time series analysis with ARIMA demonstrates no significant trend over time in ED visits post-SWL.
Figure 4.19B. Percentage of URS Treatments Requiring an ED Visit within 7 Days of Hospital Discharge in the OKSC

Abbreviations: URS- Ureteroscopy; ED- Emergency Department; OKSC- Ontario Kidney Stone Cohort.
*Predicted data points based on the time series model.
\(^a\) Time series analysis with Winters Additive exponential smoothing demonstrates a significant increasing trend over time in ED visits post-URS (10.05% -11.92%).
Figure 4.19C. Percentage of PCNL Treatments Requiring an ED Visit within 7 Days of Hospital Discharge in the OKSC

![Graph showing percentage of PCNL treatments requiring ED visits within 7 days of hospital discharge in the OKSC.](image)

**Abbreviations:** PCNL- Percutaneous Nephrolithotomy; ED- Emergency Department; OKSC- Ontario Kidney Stone Cohort.

*Predicted data points based on the time series model.

*a Time series analysis with ARIMA demonstrates no significant trend over time in ED visits post-PCNL.
Chapter 5 Discussion

The surgical management of kidney stone disease has changed dramatically over the last 20 years as a result of technologic advances, however population based studies describing these changes are lacking. More importantly, the effect of these technologic advances and the subsequent changing trends in kidney stone treatment on patient outcomes, such as re-treatment rate and post-operative morbidity, have not been accurately assessed in the “real world”. Studying these practice patterns and treatment outcomes on a large scale is important in helping identify potential public health concerns.

To our knowledge this represents the first study to use population level data to accurately describe and quantify changes in the utilization of SWL, URS and PCNL over time, as well as assess the corresponding effect on need for ancillary treatment and morbidity post-procedure.

5.1 Demographics

Over the study period, the rate of kidney stone procedures being performed per year rose steadily (Figure 4.2), which is consistent with the known increasing incidence and prevalence of kidney stone disease\textsuperscript{1-4,6}. The overall ratio of male to females in the entire cohort was approximately 1.7:1, which is keeping with previously published reports\textsuperscript{7}. Also in keeping with previous published reports showing an increase in the prevalence of stones in females\textsuperscript{1,24}, our data revealed an increase in the both the rate and proportion of females treated over time. Conversely, the rate of males treated remained relatively steady, while the proportion of males treated decreased over time. In
combination this suggests that most of the increase in kidney stone treatments over time has occurred in females.

As expected based on the known age range for the peak incidence of kidney stones, the greatest proportion of patients treated fell in the 40-64 age strata. The rate and proportions of patients 40-64 years old did rise slightly over time, while the rate in the youngest age strata (18-39) remained stable. The oldest age strata (>64 years old) demonstrated the largest increase in rate and proportion of kidney stone treatments over time. Considering that the increasing prevalence in kidney stones is in large part attributed to the rise in obesity\textsuperscript{27,28}, metabolic syndrome\textsuperscript{75} and DM\textsuperscript{76,77}, with which it is associated, it is logical that those at the greatest risk for these conditions demonstrated the largest increases in the rate of kidney stone treatments over time.

However, our results for changing age demographics over time are contrary to a recently published population based study from the UK\textsuperscript{5}. They did not demonstrate any changes in the percentage of stone formers across age groups. The age groupings were slightly different from the present study, as they divided patients in to 4 groups (0-14, 15-59, 60-74, 75+). Interpretation of their results however is limited by the fact they only report proportions and not rates over time.

5.2 Treatment Utilization

Our population-based study confirms the increased use of URS over time as suggested by physician surveys\textsuperscript{12,64} and single-centre retrospective series\textsuperscript{10,11,14}. And this increase was quite dramatic (23.69% to 59.98%). Accordingly, the utilization of SWL has decreased in a reciprocal fashion (68.77% to 33.36%).
The use of population level data in the present study has addressed some of the limitation of the existing studies on treatment trends for kidney stones. First, it has allowed a more accurate quantification in the rate change of SWL and URS use over time, inclusive of all types of centres (academic, community). Second, the nature of the universal health insurance plan in Ontario, which covers essentially all 13 million of its residents, with billing outside of the system forbidden, allowed for a complete capture of treatment trends. This overcomes the limitation of the study from the UK examining treatment trends over the last 10 years using data from the Health Episode Statistics, which tracks treatment of only those covered by the publicly funded NHS and not those with private insurance coverage.

Comparing the changes over time in percent utilization versus the standardized rate does provide some insight into the observed trends. The standardized rate of SWL utilization (64.5 to 45.2 per 100,000) did not decrease as drastically as did its percent utilization (68.77% to 33.36%), while conversely the standardized rate for URS utilization (21.2 to 67.2 per 100,000) had a more pronounced increase than its percent utilization (23.69% to 59.98%). When considering this in the context of the demonstrated increase in the overall rate of kidney stone procedure over time (Figure 4.2), it suggests the change in percent utilization is driven, in small part, by the increase use of URS as opposed to the decrease use of SWL.

By the end of 2004 URS has overtaken SWL as the predominant treatment modality in the province of Ontario (Figure 4.9). The technologic advances in fiberoptics, intracorporeal lithotripters and stone retrieval devices occurred largely in the late 1990’s and early 2000’s. Hence, a shift in the treatment paradigm at this point in time is logical,
following some time for dispersion and uptake of the new technology and techniques. Accordingly, as both the technology and skill to use this new technology continued to spread and become more accessible, the use of URS continued to rise (Figure 4.7).

The use of SWL has decreased steadily over time likely as the result of a combination of factors. First as mentioned previously, there has been little in the way of significant technologic advances or corresponding improvements in success with SWL, over the past 20 years. Conversely as discussed, URS has seen dramatic technologic advances improving its safety, and ease of use, especially for proximal ureteral stones.

Second, although access to SWL, which is a regionalized resource in Ontario (Toronto, London & Ottawa), similar to the rest of Canada, has remained stable over time, access to URS has improved. This is largely a result of smaller and safer instrumentation becoming widely available. In addition, urologists have received better technical training with this technique during their residency training, over time, as it has gained popularity, thereby increasing their comfort level with and preference for the procedure.\textsuperscript{13,65}

Lastly, physician remuneration has likely influenced the use of SWL. Very few urologists have access to treat patients directly with SWL. Urologist without treating privileges at one of the three SWL centres in Ontario must refer patients to these centres for treatment by another urologist. Conversely, many urologists now have access to the necessary equipment to perform URS at their own centre. Remembering, many kidney and ureteral stones will be amenable to treatment with either SWL or URS, it is easy to understand how both improved access and potential for financial reimbursement with URS, have likely influenced treatment modality utilization over time.
The utilization of PCNL has remained stable over time (Figure 4.8) as might be expected. There have been technological advances in intra-corporeal lithotripters (i.e., dual ultrasound and combined ultrasound + ballistic) and techniques for tract dilation (e.g. balloon) that have increased the efficiency of stone fragmentation and decreased complications with PCNL respectively, over time. However, the narrow indications for PCNL (i.e., large or complex renal stones) and the higher morbidity profile limit its more extensive use, as was seen in this study. Nevertheless, the consistent use of PCNL over time confirms that PCNL continues to have a role, most likely in treating large and complex renal stones.

The results of our study differ from the only existing study in the literature examining temporal trends in PCNL. This study, by Morris et al., examined trends in PCNL use from 1988 to 2002 in the US using the Nationwide Inpatient Sample, which represents a 20% stratified sample of all hospital discharges. They estimated the national PCNL rates using a weighted sample and found that annual PCNL use increased temporally during the study from 1.2/100,000 to 2.5/100,000 US residents (p<0.0001). Interestingly, the rate in Ontario in 1992 (7.15/100,000) already greatly eclipsed the nationwide rate in the US in 2002. The underlying reason for the greater utilization of PCNL in Ontario is unclear, however another study by Morris et al., suggests a possible explanation. In this study, they examined regional variation for PCNL in the US and showed that it has spontaneously regionalized to tertiary centers. Assuming a similar trend has occurred in Ontario, the higher use of PCNL demonstrated in the present study might be the result of better access to centres that perform PCNL. Alternatively, it might also be the result of more limited access to SWL, also used for the treatment of large
renal stones, in Ontario compared to the US. Nevertheless, the study by Morris et al. utilized a stratified sample, which is an important difference from the present study and must be considered when comparing results.

5.3 Ancillary Treatment

The need for re-treatment or auxiliary kidney stone procedures has decreased significantly over time in Ontario (22.12%-16.01%, Figure 4.10). This decreasing trend is most prominent following the year 2004, which coincides with when URS became the predominant treatment modality. Examining the ancillary treatment rates subdivided by treatment modality provides further information regarding this observed trend. URS has a consistently lower ancillary treatment rate over time compared to SWL, which was the most common procedure prior to 2004. This suggests that the decrease in overall ancillary treatment rate over time is associated with the increased utilization of URS, with its lower ancillary treatment rate. Once URS became the predominant treatment modality in 2004 this became most obvious.

In addition, the decreasing trend in need for ancillary treatment across all modalities is influenced both by the slight, but significant decreasing trend in ancillary treatment rate for URS over time and the decreasing trend in ancillary treatment rate for PCNL over time. The decreasing trend for URS, demonstrated to occur after 2004, potentially represents a learning curve, with improved results from URS as the technology became more widely available and surgeon experience increased over time. In the case of PCNL, the decreasing trend might be reflective of multiple factors, which includes technological advances in intra-corporeal lithotripters (i.e., dual ultrasound and
combined ultrasound + ballistic) and techniques for tract dilation (e.g. balloon) that have increased the efficiency of stone fragmentation and removal\textsuperscript{78-80}. In addition, as more urologists with advanced fellowship training in endourology began to practice in Ontario over time, there is collectively greater comfort and skill in performing PCNL, likely contributing to superior success with the de novo procedure and subsequently less need for ancillary treatment.

Population level data has not been previously utilized to report on the rate of repeat or auxiliary treatment. As such, our results provide an important barometer on the progress of kidney stone surgical treatment over time. Several studies including two meta-analyses\textsuperscript{8,9} have previously shown the re-treatment rate to be lower with URS, however these analyses are based on studies performed at high volume centres with access to the latest technology. Whether these results translated to all centres was certainly debatable. Furthermore, although re-treatment rates were shown to be lower with URS in these two meta-analyses, auxiliary procedures were not included in the re-treatment measurement in one of these two meta-analyses\textsuperscript{9}. We believe auxiliary procedures are as important as re-treatment in defining the need for ancillary treatment and subsequently evaluating the efficacy of treatment. Our study has successfully addressed both of these shortcomings in the existing literature. All forms of secondary procedures were included in our measure of ancillary treatment, including re-treatment and/or auxiliary treatment. Our findings confirm that the rate of ancillary treatment has decreased over time in the “real world” as was indicated in the existing body of literature.

A sensitivity analysis was also performed to assess if changes in the time frame definition of ancillary treatment impacted the outcome of the time series analysis. This
was done to address the inherent limitation in using a time frame to define ancillary treatment, which was necessitated by the constraints of the administrative datasets utilized. Interestingly, no matter the time frame definition of ancillary treatment, from those procedures occurring within as short as 60 days to as long as 180 days following the index procedure, time series analysis in each scenario showed a significant decreasing trend over time. The consistency of the results provides strong support that our surrogate measure of ancillary treatment is a valid gauge of our outcome of interest, ancillary treatment rate.

5.4 Morbidity of Treatment

Hospital Readmissions

Both the hospital readmission rate and ED visit rate within 7 days of hospital discharge increased significantly over time. Specifically, the percentage of hospital readmissions increased from 8.01% to 10.85% (p<0.0001), with the increase seen following 2004. This coincides with when URS became the predominant treatment modality. Examining the readmission rate subdivided by modality, URS is seen to have a consistently higher rate of readmission compared to SWL, over the study period. This would suggest the increase in overall readmission rate post-treatment is associated with the increased utilization of URS, with its higher rate of readmission. It is not unexpected that URS was found to have a higher readmission rate compared to SWL, as it involves a general anesthetic, instead of conscious sedation, and is a more invasive procedure involving manipulation of the urinary tract.
Interestingly, the percentage of patients requiring readmission following PCNL increased significantly over the study period from 7.11% to 12.45% (p<0.0001). This observed increase is potentially secondary to a trend towards shorter length of stay (LOS) in-hospital post-operatively with PCNL, which has been demonstrated in two prior studies. Subsequently, with patients discharged more quickly from hospital, it might then be resulting in more patients bouncing back and requiring readmission for post-procedure morbidity. One of the aforementioned studies, which was published in 2006, examined trends in PCNL in the US between 1988 and 2002, and demonstrated that the median LOS decreased from 6 days in 1988 to 1990 to 3 days in 2000 to 2002. Most likely, the median LOS has decreased even further from 2002 until the present.

The diagnosis for readmission post-treatment was not examined in this study, but evaluation of this in future studies might be helpful in devising strategies to address the higher readmission rate with URS and to better understand the observed trend for an increase in post-PCNL hospital readmission rate.

**Emergency Department visits**

Similar to hospital readmission, ED visits post-treatment also increased over time (7.58% to 9.95%, p=0.0024). When subdivided by modality, URS is seen to have a consistently higher rate of ED visits compared to SWL, over the study period (Figure 4,18A &B). This would suggest the increase in overall ED visit rate is associated with the increased utilization of URS, with its higher ED visit rate. As with hospital readmission, it is reasonable that URS has a higher ED visit rate post-procedure compared to SWL, as a result of the more invasive nature of URS.
Additionally, a significant increase in ED visit rate post-URS was revealed from 2000-2010. This might be a result of a shift towards a decreased use of stents following uncomplicated URS, with increasing evidence in the literature to support this over time.\(^8\) The theoretical advantage of leaving a temporary indwelling ureteral stent after URS is that the treated renal unit will be protected from obstruction from ureteral edema that may result from instrumentation or be caused by an obstructing ureteral stone fragment left behind. However, several studies including the AUA/EAU guidelines have shown that there is level 1A evidence to support the recommendation that stenting following uncomplicated URS procedures is optional\(^8\). Nevertheless, a widespread decrease in the use of stents might translate into more patients returning to the ED with intermittent renal colic post-URS from transient obstruction due to edema or stone fragments. The increased ED visit rate might also be a result of patients with more comorbidities undergoing URS, as the procedure gained popularity, and its improved safety and efficacy were demonstrated. Specifically, URS has been demonstrated to be safe in patients with systemic coagulopathy or taking anti-coagulant or antiplatelet medications\(^39,86\). Again, if there is widespread use of URS in anti-coagulated patients this might translate into more ED visits for post-URS hematuria or clot renal colic.

Conversely, the ED visit rate post-SWL has not changed significantly over time, however, there does appear to be a slight non-significant decrease from 2007 onwards (Figure 4.19A). With more time this decreasing rate might continue and become a significant trend. If this were the case, it might represent a reciprocal result to that seen with URS, whereby patients with certain comorbidities that increase their propensity for
post-operative complications (i.e., coagulopathies/anti-coagulant medications) are now undergoing URS instead of SWL.

No significant trend over time was seen for ED visits post-PCNL. This was contrary to expectations based on the increasing hospital readmission rate post-PCNL. However, a possible explanation for the finding of an increased hospital readmission rate post-PCNL with no change in ED visit rate post-PCNL, is that over time a greater proportion of the patients presenting to the ED post-PCNL are requiring readmission to hospital. Perhaps, although the same proportion of patients are presenting to the ED post-PCNL, the gravity and complexity of their presenting complaints has increased, resulting in more patients requiring admission to hospital for definitive management. The increased gravity and complexity of their presenting complaints could be explained by the aforementioned demonstrated decrease in median LOS post-PCNL\textsuperscript{5,84}, which theoretically might put patients at a greater risk of suffering a complication or morbidity post-procedure requiring readmission.

Ultimately, future studies with this dataset examining the diagnostic codes for ED visits post-treatment would help to further clarify the observed ED visit trends. In particular, examining the use of stents over time and correlating the presence of a stent with ED visit, in this dataset, might help to clarify the post-URS ED visit trends. In addition, examining the proportion of ED visits post-PCNL that result in hospital admission and the changes in diagnostic codes for post-PCNL ED visits over time might help to clarify the observed post-PCNL ED visit rates.
5.5 Limitations

The results of this study must be interpreted within the context of the study limitations. First, this is an ecologic study and as such is at risk for the ecological fallacy. The results of this study represent aggregate statistics that accurately describe all patients treated for kidney stones in the province of Ontario, but may not accurately describe individuals within this group.

As mentioned, the province of Ontario has a single payer universal healthcare system and SWL is a regionalized resource within the province. As such, the results of this study may not necessarily be generalizable to a different healthcare system, with differences in physician supply and remuneration, as well as differences in access to resources, specifically SWL.

Unfortunately, secondary to the observational nature of this study we cannot determine the underlying causes of and their relative contribution to the observed shift in the treatment paradigm for kidney stone disease. Although advances in technology and technique have certainly played a central role in the changing treatment patterns over time, financial reimbursement and access to resources are also likely factors contributing to the observed trends. As discussed above, most urologists will have access to the instrumentation necessary for URS at their institution, while only three SWL treatment centres exist, each at an academic site.

Ideally, one of the principal outcomes of the study would have been to measure treatment success (i.e., stone-free rate) over time, to evaluate how the efficacy of treatment has been impacted by the changing treatment trends. Unfortunately, due to the limitations associated with utilizing administrative data, we have no means of directly
assessing treatment success, which is determined based on imaging studies (e.g., x-ray, ultrasound or computed tomography scans).

Accordingly, the need for repeat or auxiliary procedures was chosen as a proxy of success, as this outcome was more amenable to assessment given the confines of the administrative data utilized. Nevertheless, this outcome also has its inherent limitations, as we did not have a true measure of need for ancillary treatment within the administrative datasets. Instead, in this study we relied on a surrogate measure based on the time frame definition of 90 days. However, this introduced the risk of a potential misclassification bias. Meaning that a patient receiving a second stone treatment within 90 days will be classified as requiring an ancillary treatment when in fact they might have been undergoing treatment of a second stone on the same side or a separate stone on the contralateral side. Similarly, a patient receiving an ancillary treatment of the same stone greater than 90 days following initial treatment will be classified as having 2 index procedures.

To address this potential limitation we performed a sensitivity analysis. The sensitivity analysis supports a significant trend over time for a decreasing need for ancillary treatment, no matter the exact time frame definition utilized. As such, although misclassification is likely present it doesn’t appear to be a source of bias in the results of this outcome, in this study.

Unmeasured confounders also represent a potential limitation of the present study. The most important unmeasured potential confounder is stone demographics, specifically stone composition, size and location. All three of these stone characteristics are key determinants of the treatment modality utilized and the subsequent likelihood of
treatment success. Unfortunately, none of these parameters are captured in the administrative databases employed in this study.

At present there is no strong evidence to suggest there has been a change in the size or location of stones over time. Conversely, the epidemiology of stone composition has been shown to have changed slightly over time, specifically, the incidence of uric acid stones has increased (~3%)\(^87-89\). This increase is secondary to the rising incidence of diabetes mellitus and obesity, with which uric acid nephrolithiasis are associated\(^76,77,90-92\). Uric acid calculi are predominantly radiolucent and as such are often not amenable to treatment with SWL, which requires fluoroscopy for targeting of the stone. Instead, uric acid calculi are usually best treated with URS, unless very large. This change in stone composition would favor greater utilization of URS, however the small increase in the incidence of uric acid stone disease would not account for the dramatic increase in the utilization of URS that was seen in this study.

5.6 Clinical Significance and Implications

Kidney stone disease is a major clinical and economic burden for health care systems. International epidemiological data suggest that the incidence and prevalence of stone disease is increasing\(^1-6\). The findings of the present study point towards an increase in the prevalence of stone disease in the province of Ontario, as the rate of kidney stone procedures has increased steadily over time. The increased volume of kidney stone procedures over time, as well as the shift in the treatment paradigm towards URS, has important implications for work force planning, training and service delivery moving forward. The results of the present study have established the current state of the surgical
management of kidney stone disease in Ontario. URS has become the most commonly utilized modality and we have seen a corresponding decrease in the need for ancillary treatment, but an increase in post-procedure morbidity. These results provide the framework for future studies to evaluate how to optimize the outcomes and cost-effectiveness of kidney stone treatment in Ontario.

Lastly, our findings provide an indication that future research and developmental efforts must be focused on addressing prevention of stone disease to counteract the ongoing rise in kidney stone procedures and the associated rising cost of management.

5.7 Future Directions

This study has made several important findings, however some of these will need to be examined in further detail in future studies. Specifically, as mentioned above, morbidity trends including increases in hospital readmission post-PCNL and ED visits post-URS will need to be examined more closely to understand the etiology of the observed trends.

Based on the objectives of this study, examination of hospital readmissions and ED visits post-procedure included all diagnostic codes. It would be interesting and valuable in future studies with this dataset to assess the breakdown of procedure-specific and non-procedure specific diagnostic codes for hospital readmissions and ED visits. This will allow for the assessment of both significant trends over time and differences across the three treatment modalities. Considering that the proportion of hospital readmissions and ED visits have increased over time, delineating the common diagnoses and any
observed diagnostic trends could help to develop strategies aimed at reducing morbidity post stone procedures.

The potential role of access to specific treatment modalities, especially SWL centres, will need to be evaluated to better understand the causes for the observed shift away from SWL and towards URS. Regional variation analysis of stone treatment across the 49 counties of Ontario might help to shed light on this, as would assessing the predictive role of provider factors (e.g., institution type, physician years in practice) on mode of treatment.

A cost-effectiveness analysis of SWL versus URS is an important next step in determining whether the observed trends in stone treatment represent the optimal use of healthcare resources from a system standpoint. Specifically, does the decrease in ancillary treatment associated with the increased use of URS outweigh the increase in post-procedure morbidity?

Lastly, some studies suggest that the use of SWL results in an increased propensity for stone formation in the future due to failure of clearance of small stone fragments. Using the 20 years of population based data from Ontario this could be evaluated by assessing the effect of treatment modality (SWL vs. URS vs. PCNL) on future risk for developing kidney stones requiring intervention.

5.8 Conclusions

The focus of this thesis was to evaluate trends over time in the surgical management of kidney stone disease in the province of Ontario from 1991 to 2010. We have established that there has been a shift in the treatment paradigm of kidney stones
away from the utilization of SWL and towards the use of URS. Associated with these changes in treatment utilization have been a significant decrease in the need for ancillary treatment and a significant increase in the hospital readmission and ED visit rate post kidney stone treatment.
**Glossary of Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARIMA</td>
<td>Autoregressive Integrated Moving Average</td>
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<tr>
<td>AUA</td>
<td>American Urological Association</td>
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<tr>
<td>BMI</td>
<td>Body Mass Index</td>
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<tr>
<td>CI</td>
<td>Confidence Interval</td>
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<tr>
<td>CIHI</td>
<td>Canadian Institute for Health Information</td>
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<tr>
<td>DAD</td>
<td>Discharge Abstract Database</td>
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<tr>
<td>DM</td>
<td>Diabetes Mellitus</td>
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<tr>
<td>EAU</td>
<td>European Association of Urology</td>
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<tr>
<td>ED</td>
<td>Emergency Department</td>
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<td>MET</td>
<td>Medical Expulsive Therapy</td>
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<tr>
<td>NACRS</td>
<td>National Ambulatory Care Reporting System</td>
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<tr>
<td>OHIP</td>
<td>Ontario Health Insurance Plan</td>
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<tr>
<td>OKSC</td>
<td>Ontario Kidney Stone Cohort</td>
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<tr>
<td>PCNL</td>
<td>Percutaneous Nephrolithotomy</td>
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<td>RCT</td>
<td>Randomized Controlled Trial</td>
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<td>SDS</td>
<td>Same Day Surgery</td>
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<td>SWL</td>
<td>Extracorporeal Shockwave Lithotripsy</td>
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<td>UK</td>
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<td>URS</td>
<td>Ureteroscopy</td>
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<td>US</td>
<td>United States</td>
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References


randomized trial of extracorporeal shock wave lithotripsy.


51. Evan AP, McAteer JA, Connors BA, Blomgren PM, Lingeman JE. Renal injury during shock wave lithotripsy is significantly reduced by slowing the rate of shock wave delivery. *BJU Int.* Sep 2007;100(3):624-627; discussion 627-628.


Appendix A

Table of Time Series Model Selection

All time series models were thoroughly evaluated as described in the method section (3.9.2 Time Series Analysis). The exponential smoothing and ARIMA model of best fit for each time series with their associated Schwarz Bayesian Information Criterion (SBIC) values are provided in the table below.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Time Series Model*</th>
<th>SBIC**</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWL Treatment Utilization (%)</td>
<td>1. <em>Winters Multiplicative Exponential Smoothing</em></td>
<td>1. 66.77</td>
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<td></td>
<td>2. ARIMA</td>
<td>2. 80.47</td>
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<td>URS Treatment Utilization (%)</td>
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<td></td>
<td>2. ARIMA</td>
<td>2. 50.38</td>
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<td>PCNL Treatment Utilization (%)</td>
<td>1. <em>Winters Additive Exponential Smoothing</em></td>
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<td>2. ARIMA</td>
<td>2. -36.71</td>
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<td>SWL Treatment Utilization (Pop. STD Rate)</td>
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<td>2. 40.71</td>
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<td>2. ARIMA</td>
<td>2. 19.61</td>
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<td>PCNL Treatment Utilization (Pop. STD Rate)</td>
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<td>2. ARIMA</td>
<td>2. -29.64</td>
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<td>2. ARIMA</td>
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<td>2. 99.85</td>
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<td>Ancillary Treatment (90 days)-URS</td>
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<td>2. 50</td>
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<td>2. ARIMA</td>
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<td>Outcome</td>
<td>Time Series Model*</td>
<td>SBIC**</td>
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</tr>
</tbody>
</table>
| Ancillary Treatment (90 days)- PCNL| 1. Double (Brown) Exponential Smoothing  
2. ARIMA                      | 1. 179.90  
2. 178.58 |
| Ancillary Treatment (60 days)- All Modalities | 1. Winters Additive Exponential Smoothing  
2. ARIMA            | 1. 14.92   
2. 20.59 |
| Ancillary Treatment (120 days)- All Modalities | 1. Log Linear (Holt) Exponential Smoothing  
2. ARIMA            | 1. 35.74   
2. 36.91 |
| Ancillary Treatment (180 days)- All Modalities | 1. Log Linear (Holt) Exponential Smoothing  
2. ARIMA            | 1. 45.80   
2. 49.16 |
| Hospital Readmission- All Modalities | 1. Log Linear (Holt) Exponential Smoothing  
2. ARIMA            | 1. -20.23  
2. -10.43 |
| Hospital Readmission- All Modalities- SPLIT PRE 2004 | 1. ARIMA  | 1. 0.0034  |
| Hospital Readmission- All Modalities- SPLIT POST 2004 | 1. Double (Brown) Exponential Smoothing  
2. ARIMA            | 1. -11.36  
2. -16.44 |
| Hospital Readmission- SWL            | 1. ARIMA                      | 1. 4.21   |
| Hospital Readmission- URS            | 1. ARIMA                      | 1. 79.05  |
| Hospital Readmission- PCNL           | 1. Winters Additive Exponential Smoothing  
2. ARIMA                      | 1. 141.33  
2. 138.36 |
| ED Visit- All Modalities             | 1. Winters Additive Exponential Smoothing  
2. ARIMA                      | 1. -23.22  
2. -12.57 |
| ED Visit- SWL                        | 1. ARIMA                      | 1. -20.12 |
| ED Visit- URS                        | 1. Winters Additive Exponential Smoothing  
2. ARIMA                      | 1. 1.49    
2. 13.30 |
| ED Visit- PCNL                       | 1. ARIMA                      | 1. 79.03  |

*In cases where only the ARIMA model met the necessary assumptions and parameters no exponential smoothing model is listed.

**The model with the lowest SBIC was chosen as indicated by **bold italic** font.