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Historical Aspects from Ancient to Modern Era with Advanced Techniques for Nephrolithiasis: A Review

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ABSTRACT

The history of urinary stones almost starts and goes hand in hand with civilization history. Modern science and philosophy has its origins in the Ancient Egyptians, through whom we see the first traces of social and technological innovations. In 1901, English archaeologist E. Smith near El Am rah, Egypt discovered a bladder stone from a 4500–5000 year-old mummy. The stone is a calculus of mineral or organic solid that can develop anywhere in the urinary tract. Subsequent developments in urology include the introduction of percutaneous nephrolithotomy (PCNL) and the search for even less invasive treatments for stones, leading to the use of various energy sources for stone fragmentation.

Keywords: Ancient period, renal stones, PCNL, lithotripsy, ESWL

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INTRODUCTION

Kidney stones or Renal Calculi (from Latin *renes*, "kidney" and calculi, *"pebbles"*) are solid structures composed of urinary precipitates and crystals.[1,2] These stones can range in size from less than a millimetre to few centimetres.[1]

The term 'Crystal' derived from the Greek word '*Krystallosus*', meaning ‘ice’, which is used to refer to the solid state of substances with a particular internal structure and a symmetrically arranged planer surface.[3]

Nephrolithiasis — from the Greek word *nephros*, meaning "kidney" and *lithos*, meaning "stone" refers to the condition of having stones in the kidney or collecting system.[4,5] The stone is a calculus of mineral or organic solid that can develop anywhere in the urinary tract (urolithiasis) or in the ureter (ureterolithiasis) more precisely. As the stone moves through the urinary tract, it can either be expelled uneventually (asymptomatic crystalluria) or obstruct the urinary flow as it travels, causing "colicky" pain. Renal colic is characterized as severe intermittent flank pain that radiates to the groin, lower abdomen or genitalia because of a stone's passage through the urinary system. Pain is often accompanied by nausea, vomiting, dysuria and haematuria.[6] High incidence areas of kidney stone in the world are Scandinavian countries. Mediterranean countries, British Isles, Northern Australia, Central Europe, portions of the Malaysian peninsula, China, Pakistan and Northern India, whereas the incidence of kidney stone formation is lower in areas like Central and South America, many areas of Africa. In Asia stone forming belt has been reported to stretch across Sudan, Saudi Arabia, the United Arab Emirates, the Islamic Republic of Iran, Pakistan, India, Myanmar, Thailand and Philippines.[2,7]

In India “the stone belt” occupies parts of Maharashtra, Gujarat, Punjab, Haryana, Delhi and Rajasthan.[7] Renal stone disease has been recognized in many parts of the world since ancient era. It is one of the most painful and commonest urological diseases. The evidence of urinary calculi has been found in 7000 years old Egyptian mummy. Its incidence has increased considerably during the 20th Century. The Indian subcontinents included in the stone belt region, consistently high incidence of renal calculi have been reported.[8] It is estimated that at least 10 per cent of the world's population in industrialized part of the world is suffering from urinary tract stone disease. Kidney stones are common in industrialized nations with an annual incidence of 0.5% to 1.9 %. Upper and lower urinary tract stones also occur in India, but there is wide regional variation in incidence. A high and growing incidence of urolithiasis was recorded in Udaipur and some other parts of Rajasthan in west India.[9]

REVIEW OF LITERATURE

HISTORICAL ASPECT

Ancient times

The history of urinary stones almost starts and goes hand in hand with civilisation history. Modern science and philosophy has its origins in the Ancient Egyptians, through whom we see the first traces of social and technological innovations. In 1901, English archaeologist E. Smith near El Amrah, Egypt discovered a bladder stone from a 4500–5000 year-old mummy. Treatments for stones were mentioned in ancient Egyptian medical writings from 1500 BC.[10]

India

Evidence of stone disease is also found in the Sushruta Samhita, a collection of texts on the practice of traditional medicine by the Hindus in ancient India. The estimated date of these works is 600 BCE to 600 AD. Sushruta attributed four entities to the cause of the calculi, i.e. phlegm, bile, air or semen, and gave the following description of their presentation; ‘When air and phlegm meet, a small stone is formed which grows towards the bladder outlet

and hinders the outflow of urine. The tortured patient then grinds his teeth, presses on his abdomen and rubs his penis. Urine, flatus and faeces are passed with severe pains. In such a case, the stone is black, rough, irregular and covered with spikes like the maneleacadamba flower'.[11]

Many medical treatments were recommended for stone sufferers in ancient India, a vegetarian diet, a urethral syringe of medicated milk, clarified butter, or alkalis. Only when these treatments failed was surgery used. Sushruta was among the first to describe in great detail the lithotomy. He listed preoperative preparations to include anointing the body, cleansing of the system with emetics and purgatives, and prayers and offerings to the gods.[12] He proceeded to detail the position of the patient who 'lies on his back, placing the upper part of the body in the attendant's lap, with his waist resting on an elevated cloth cushion, knees and elbows contracted and bound'. The attendant is described as a person of 'strong physique and un agitated mind'. Then the surgeon rubbed the clarified butter on the left side of the umbilical region and pressed his fist tightly down until the stone was as low as possible'. Sushruta's description of the operation is intriguing. 'The left index and middle fingers, with cut nails, are dipped in oil and introduced into the rectum, and then are pressed forwards until the stone is grasped and stands out like a tumour'.[13] The actual surgical procedure is described meticulously, 'An incision should then be made on the left side of the raphe of the perineum at the distance of a barley corn and of sufficient width to allow the free egress of the stone. Several authorities recommend the opening to be on the right side of the raphe of the perineum for the convenience of the operation. Special care should be taken in removing the stone from its cavity so that it would not break into pieces or leave any broken particles behind, however tiny, as they will in such a situation, would certainly grow bigger'. Sushruta proceeds to give postoperative instructions for the patient to sit in warm water, which was thought to prevent the accumulation of blood in the bladder. However, if blood does accumulate in the bladder, he states, 'a decoction of the Kshira-trees should be injected into the bladder with the help of a urethral syringe'.[14]

Persia

The Middle East had a pivotal role in the history of Urology.[15,16] Three important figures in medicine during the middle ages were of Persian origin: *Muhammad Ibn Zakariya al-Razi* (ca. 865-925 AD), *Ali Ibn al-Abbas al-Majoosi* (930-994 AD), and *Abu Ali al-Husain Ibn Abdullah Ibn Sina* (981-1037 AD), who are known to the West as *Razes*, *Haley Abbas*, and Avicenna respectively.[17] The traditional Persian medicine system dating back to 1000 BCE explains even the symptoms of stone disease and proposes treatment methods, e.g. baths, scorpion oil massages and avoidance of eggs, fresh or hard-boiled, meat and fish. Other treatments include rose water, Indian beans, melon pips and a combination of substances where 'one crushes melon and cucumber pips with radish, turnip and carrot seeds, and after the mixture has been boiled and filtered, the infusion is taken with a puree of radishes'.[18]

Greece

The first remarkable discoveries and documentations concerning urinary stone disease were made by ancient Greeks, who established the foundations of philosophy and science. Hippocrates (460–377 BC) described kidney disease, and identified bladder stone symptoms. In his famous *Oath of Medical Ethics* for physicians, he underlines *"I will not cut for the stone, but will leave this to be done by practitioners of this work"*.[19,20] Around that time, special lithotomists performed lithotomy with only perineal incision and Hippocrates claimed adamantly that bladder wounds were lethal. This admonition to physicians about a very risky procedure was to be held for centuries.[20] Ammonius of Alexandria (276 BC) was the first person to recommend that the stone be crushed to facilitate its removal. He secured the stone with a hook and then used a thin blunt-ended instrument to break the stone. Since he was the first to use the word "lithotomus" to cut the stone, the nickname has been given to him. However, his idea did not gain popularity at that time.[20] The first descriptions of "perineal lithotomy" recorded were those of Cornelius Celsus (25 BC–40 AD), who lived in Rome and wrote a medicine encyclopaedia (De Medicina). While he never carried out the operation himself as a surgeon, his definition of perineal lithotomy was a milestone in the history of urology. This technique, appropriately called the "Operation Minor" or "petit appareil", was used with very little change, indeed if any, for the next 1500 years. With the aid of two good as well as intelligent assistants, Celsus suggested the operation to be carried out in spring, between the ages of 9 and 14. Many outstanding Greek physicians who practiced lithotomy were Calus Plinus Secundus (23–79 AD), Galen (131–200 AD), and Paul of Aegine (625–690 AD), as defined by Celsus.[21]

Rome

Cornelius Celsus (25 BCE to 40 AD), who lived in Rome during the early Christian period, wrote an encyclopedia of medicine. *'De Medicina'* was a systematic survey of medicine and included the works of Hippocrates.[22] His description of lithotomy was a landmark in the history of urology, as it was practised with very little change, indeed if any, until the 18th century. He advised the procedure to be carried out only in the spring, between the ages of 9 and 14 years, and was suitable for females and males. Galen (131–200 AD) meaning 'peaceful one', from Pergamum, was a follower of Hippocrates, whose works he reinstated. Many consider Galen second only to Hippocrates in fame and importance. He added to the growing literature for stone disease with his view that abscesses, ulceration of the kidney and haematuria were conditions caused by calculi, in the form of sand or larger stones. He continued the practice of lithotomy as described by Celsus.[12]

Arab

Ancient Arabic medicine was based mainly on classical Roman and Greek works. Rhazes (841–926 AD), who wrote a 23-volume account of his works, described lithotomy in the same manner as that carried out by Paul of Aegina. In the 10th volume of 'The Continens' he describes a new technique for breaking large bladder stones, which are held using a strong pincer. He believed that renal calculi were caused by excess heat or salt. His prescriptions for stones included birthwort, wormwood and pepper for small stones, and the penis was rubbed with scorpion oil. Shortly afterwards, Albucasis (936–1013AD) of Cordoba, demonstrated considerable experience in surgery by modifying the technique of lithotomy as practised by Celsus and Paul of Aegina.[12,20] He used a scalpel,

called a '*nechil'*, to make his transverse incision, and suggested 'if the stone is large, it is unwise to make a long incision; the patient would die or incontinence would result, for a wound in this situation may not heal; it is better to crush the stone, especially if it irregular in shape'. Once again, a method had been described to crush the stone, but not adopted widely.[12] Albucasis did not operate on females for religious reasons, and midwives under the surgeon's directions performed operations on women. He furthered Rhazes' ideas by designing special forceps, which he used to grasp the stone firmly. This, the Albucasis forceps, became known as the primitive lithotrite.[23] He also designed a drill called '*michab'*, which he used for, impacted urethral calculi. The michab was placed in contact with the stone in many places, thereby fragmenting it. When the penis was squeezed, the fragments washed out with the urine. Many have referred to this device as the foundation of true lithotripsy.[24,25]

The medieval period (1096–1438)

Chauliac (1300–1367), who was considered the father of French surgery, wrote the Chirugia Magma in the 14th century, incorporating surgical techniques from the Arabs, the Greeks and his experiences. He wrote a lot about stone disease but never performed lithotomy, which at that time was a dangerous procedure. While some separation of surgery from medical practice had begun to develop in early medieval times, the Fourth Lateran Council stressed this in 1215, a papal edict that forbade doctors (most of whom were clergy) from performing surgical procedures, since contact with blood or body fluids was regarded as contaminating to men. As a result, surgery practice was reduced to craft status with apprenticeship training by guilds.

The Renaissance (1453–1600)

New trials on offenders may be prosecuted during this time. As a result, Colot suprapubically separated stones from a suspect in 1475. Later in France, the Colot family retained some form of lithotomy monopoly over 2 centuries. They were members of the Surgery College, and had a high reputation. However, in 1520 Farncisco de Romanis did the first significant scientific advance after Celsus and Albucasis. He implemented a sound to classify the bladder neck, and a broad knife called "novacula" was used to make the perineal incision onto the sound. He also used explorative retractors. His technique was popularized as "Marian operation" or "Grand Appareil," by his student Marius Sanctus. There were five general types of lithotomy: The Celsian, or 'lesser operation', the Marian, or 'greater operation', the lateral operation; suprapubic cystotomy, or 'high operation', and cutting through the rectum, or proctocystotomy. Each of these methods represented surgical advances corresponding more or less to historical eras.[26] A new technique of transurethral stone fragmentation and bladder irrigation was independently identified by two Turkish physicians, Sabuncuoglu Serafettin and Ahi Ahmed Celebi, almost at the same time in the 15th century. They also wrote detailed prescriptions in their texts to aid passage and dissolution of stone. The greatest French surgeon of his day, Pare (1510–1590), also wrote a detailed chapter on urinary stone disease and lithotomy, although he never performed it. He also wrote lengthy and comprehensive prescriptions in his book for stone patients. Pierre Franco also performed the first recorded removal of a calculus by suprapubic lithotomy during the Renaissance, in 1561. Though his patient recovered well, Franco advised others not to follow his example, due to this approach's extreme hazards. During the Renaissance, the first record of an operation carried out on the

kidney was also about this time. In 1550, Cardan of Milan opened a lumbar abscess, and he found 18 stones. However, there was no further mention of this procedure for many years.[20]

The 17th century and onwards

During the early part of the 17th century Covillard was the one of the first lithotomists to advise crushing a stone to facilitate its removal, 'if the stone is adherent, it must be crushed in an forceps and the pieces removed by a curette'. Around the same time, in 1651, Jan de Doot, a blacksmith in Amsterdam who it seems had undergone a previous failed lithotomy, performed a lithotomy on him. Using a kitchen knife, he removed a 'four ounce palpable stone' from his perineum.[12] Jacques de Beaulieu (1651–1714), who invented "lateral lithotomy," was the next significant influence on lithotomy practice. Thereafter, Ferre Jacques, who conducted more than 5000 operations, further refined and popularized this system.[20] William Cheselden (1722) and John Douglas (1719) were the first to realize that distended bladder mowed upwards and therefore an extra peritoneal approach was possible. However, these two famous friends accused each other of plagiarism, which lasted for many years.[20] With the prominent persons harboring the condition, the history of urinary stones is becoming more appealing. King Leopold I of Belgium, Peter the Great, Louis XIV, George IV, Oliver Cromwell, Benjamin Franklin, the philosopher Bacon, the scientist Newton, the doctors Harvey and Boerhaave and the anatomist Scarpa are prominent historical figures who developed bladder stones.[20]

Development of lithotrity

The 19th century saw the modification and acceptance of lithotrity, which did not require incisions. Of course, lithotrity was not a new idea. Albucasis had already developed a 'primitive lithotrite' and over time many people have, against popular belief, crushed the stone to facilitate its removal.[12]

Table: Developments of lithotripsy over the last century.

Method/ year	**Detail**
PCNL	
1955	Goodwin; the first Percutaneous nephrostomy.
1976	Dilatation of the channel to aid stone extraction.
Ultrasonic lithotripsy	
1953	Mulvaney discovered the sound waves that fragmented stones.
1977	Kurth first applied the technique to renal stones.

Electro hydraulic lithotripsy	
1913	Wappler states: 'When this spark is brought into contact with both the hard and soft species of bladder calculi, it causes them to disintegrate'.
1950	Yutkin obtains a patent for electro hydraulic shock Waves.
1967	URAT-1 is displayed and popularized
Laser lithotripsy	
1961	Development of Nd: YAG, a solid state laser.
Pneumatic or ballistic lithotripsy	
1992	Swiss Lithoclast described.
ESWL	
1966	Dornier employee touched a plate hit by a high velocity projectile and described an electric shock.
1973	First *in vitro* destruction of stone reported.
1980	First patient treated with Dornier HM-1 lithotripter.
1983	First commercially available lithotripter, Dornier HM-3.

Subsequent developments in urology include the introduction of percutaneous nephrolithotomy (PCNL) and the search for even less invasive treatments for stones, leading to the use of various energy sources for stone fragmentation.[12]

Advanced Techniques of Nephrolithiasis:

(a) ESWL
(b) Ultrasound Lithotripsy
(c) Elecrohydraulic Lithotripsy (EHL)
(d) Percutaneous nephrolithotomy (PCNL)
(e) Ureteric catheterization and DJ Stenting
(f) Dormia Basket
(g) Push Band
(h) Litholopaxy
(i) Laser Lithotripsy
(j) Uretero-renoscopy (URS)[27,28,29,30,31]

● **Extracorporeal shock wave lithotripsy (ESWL):**

► It is the modern method of non-operative treatment of renal stones.[28]

► *Piezo-Ceramic* or *Electromagnetic* shock waves are passed to the stone through water bath or water cushion which acts as a media. Shocks are produced at 2/sec. 1000-4000 shocks are required for each stone.

► *Dornier Lithotripter* is used for fragmenting stones.

► Stone is located and observed through fluoroscope (C-Arm) or ultrasound. It causes shock waves to generate compressive waves over the stone, to break it. These fragments are flushed out later.[30]

Advantages

► No anaesthesia is required.

► Can be done as an OP procedure.

► Less than 2.5 cm sized stones are well fragmented.

► Hard stones, oxalate stones are better eliminated by ESWL.

► ESWL can be done repeatedly in different sittings.

► If it is not successful one can switch over to PCNL.[30]

Complications

► Pain due to blockage of the ureter by the fragments.

► Infection by the organisms released from the stones when broken.

► Recurrent calculus from the retained fragments acting as a nidus.[28]

● Ultrasound Lithotripsy:

Ultrasonic lithotripsy is most commonly utilized for dealing with larger stone burdens such as during PCNL and cystolithopaxy for bladder calculus. The advantages of ultrasonic lithotripters include a proven safety record, minimal effects on compliant tissue (tissue does not resonate with vibration energy), and the ability to evacuate stone material with hollow probes during fragmentation. While this modality can be used in association with rigid ureteroscopy, the large probe size and rigid nature of the probe limit its utility in this context, making other alternatives more attractive. Another downside is the risk of overheating because of the conversion of vibration energy to heat energy. Sufficient irrigation is necessary for cooling to prevent tissue damage. The fragmentation rate is 97–100%. The recently reported stone free rate is 94%.[32]

● Elecrohydraulic lithotripsy (EHL):

Electrohydraulic lithotripsy (EHL) can be used during ureteroscopy, percutaneous nephrolithotripsy (PCNL) and for fragmentation of bladder stones. Currently the most common use for EHL is in association with ureteroscopic stone removal with either rigid or flexible instruments. While EHL may be used during PCNL, it usually would not be the preferred modality for debunking and dealing with the major portion of a stone because it produces large fragments, causes tissue trauma and bleeding, and occasionally fails to fragment the hardest stones (calcium oxalate monohydrate). In addition, it does not evacuate fragments. This method is a useful alternative; however, when performing flexible nephroscopy and fragmenting stones inaccessible to rigid endoscopes during PCNL.[32] The stone free rate is 66% for the renal calculus, 70% for the proximal ureter, 90% for the mid-ureter and 83% for the

distal ureter. The fragmentation rate is 84– 90%. There have not been any new developments of EHL technology published for several years.[32]

● Percutaneous nephrolithotomy (PCNL):

This is a minimally invasive technique for extraction of renal stones. A hollow needle is passed percutaneously into the renal collecting system through the renal parenchyma. A guide wire is inserted through the needle and the needle is then withdrawn. Following the guide wire the track is dilated using a series of dilators. The nephroscope is then inserted, through this dilated tract. Small stones can be extracted under vision. The larger stone needs to be fragmented by an ultrasound or by an electro hydraulic probe and the fragmented pieces are removed by using a nephroscope.[28,30] The aim is to remove all fragments if possible, and this may take some time if the calculus is large. When the procedure is over, the device is left with a nephrostomy drain. This decompresses the kidney and allows repeated access if stones particles remain. When treating complex (stag-horn) calculi, percutaneous nephrolithotomy is often combined with ESWL. The surgeon removes the central part of the stone percutaneously and the more peripheral fragments are treated by ESWL.[33]

Indications

PCNL is useful for calculi more than 2.5cm in diameter which are not suitable for ESWL, hard stones and ESWL failure cases.[28,30,34]

Complications

• Haemorrhage from the punctured renal parenchyma.[33]

• Perforation of the collecting system with extravasation of saline irrigant.[33]

• Injury to colon or pleura while creating initial track for nephroscope.[30,33]

• Sepsis.[28]

● Dormia basketing:

Basket is passed into the proximal ureter beyond the stone and opened. The stone is then pulled out.

Indications for Dormia basketing:

• Stone in lower third ureter

• Stone below pelvic brim

• Stone less than 10 mm size

• Single stone.

Complications of Dormia basket

• Stone dislodgement

• Urethral injury

• Avulsion of ureter

• Stricture ureter.[30]

● **Laser lithotripsy:**

Laser technology in urine stone fragmentation was first clinically introduced in the late 1980s. The main advantages of all laser lithotripter devices is that they are thin and flexible, they can be employed in all endoscopic instruments and permit successful access to all parts of the urinary tract. Their disadvantages are a low fragmentation effect for large stones and they are relatively highly priced. Some can cause tissue damage and tissue ablation through a thermal effect, proportional to the applied energy. They can also damage baskets and wires into the urinary tract when employed simultaneously. Another disadvantage of some laser lithotripters is their inability to fragment certain stones.[32] YAG laser lithotripsy is a highly efficient and safe form of treatment for outpatient control of ureteral and a proportion of intrarenal calculi. The effectiveness and flexibility of the holmium laser in combination with small rigid or flexible endoscopes make it our preference of ureteroscopic lithotripsy.[35]

● **Ureterorenoscopy (URS):**

Through ureteroscope, stone is visualised and often fragmented using pneumatic bombarder. It is then extracted by ureteroscope.

Complications are perforation of ureter and extra peritoneal leakage of urine, bleeding.[30]

B. Operative Methods:

i. Pyelolithotomy
ii. Extended pyelolithotomy
iii. Nephrolithotomy
iv. Pyelonephrolithotomy
v. Partial nephrectomy
vi. Bench surgery
vii. Coagulum pyelolithotomy
viii. Anatrophic pyelolithotomy
ix. Nephrectomy

i. Pyelolithotomy — Suitable for stones in extra renal pelvis. By loin (posterior sub costal) incision, kidney is approached. Renal pelvis is opened, the stone is removed and the pelvis is closed. A drain is placed and wound is closed.[30]

ii. Extended pyelolithotomy (Gil-Vernet) — In case of intrarenal pelvis, incision is done on the hilum between the pelvis and kidney over the renal sinus, dissection is carried out so as to remove the stones from pelvis as well as calyces.[30]

iii. Nephrolithotomy — By placing incision just behind the most convex surface *(Brodel's line)*, stone is removed.[30] Here the pelvis is intrarenal and the stone is taken out through the kidney parenchyma.[28]

iv. Pyelonephrolithotomy — Stone is extracted through an incision in the pelvis as well as the renal parenchyma.[67] It is often done in staghorn calculus.[30]

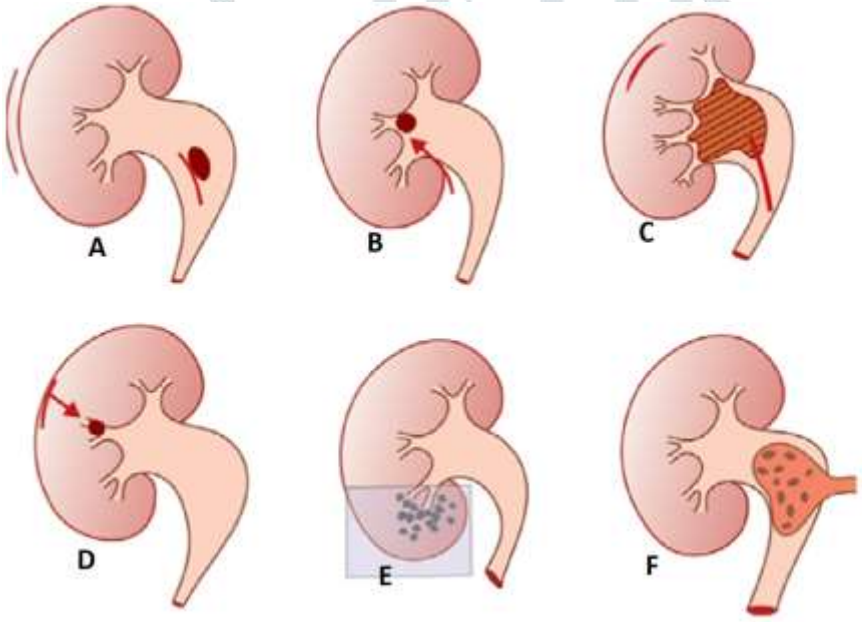
v. Partial nephrectomy — It is done when there are multiple stones occupying a pole, usually lower pole of the kidney or when there is damage to the calyx, if not removed may encourage further stone formation.[30]

vi. Bench surgery — Kidney is removed out temporarily, cooled by ice packs or inosine or liquid nitrogen. Stones are searched and removed completely. Later kidney is replaced in right iliac fossa.[30]

vii. Coagulum pyelolithotomy — Coagulum solution which contains fibrinogen is poured into the renal pelvis. It is activated so that it solidifies, meanwhile entang ling the stones in renal pelvis. This entangled mass is removed en masse.[30]

viii. Anatrophic pyelolithotomy — It is cooled with ice packs for 20 minutes after exposure of the kidney, and the posterior branch of the renal artery is temporarily clamped using bull-dog clamps. The most avascular plane behind the Brodel's line is thus visualised properly. Kidney is opened through this line and stone/stones are removed (anatrophic means "to prevent atrophy").[30]

ix. Nephrectomy — When the kidney is destroyed by pyonephrosis following obstruction by stone nephrectomy is performed.[28]



Figs: A to F: Surgeries for renal stones. (A) Pyelolithotomy (B) Extended pyelolithotomy (C) Nephropyelolithotomy (D) Nephrolithotomy (E) Partial nephrectomy (F) Coagulum pyelolithotomy.[30]

CONCLUSION:

Nephrolithiasis has its roots deeply embedded in the urological literature. Treatments have changed drastically over the centuries, from litholytic agents that dissolve calculito open surgical procedures to remove bladder calculi, with Hippocrates admonition not to enter the bladder. Even lithotomy has progressed from entry through the perineum, then suprapubically and finally endoscopically. Such controversy has surrounded the history of stone disease that Shakespeare commented, *'Blessed be the man who spares these stones and cursed being the man who moves these bones'* (Shakespeare's own epitaph). Surgery to the kidney was not really accepted until the 19th century, and it is only in the last few years that 95% of stones that previously required open surgery are

being treated with more conservative measures. This has become possible as a result of the technological advances, scientific discoveries and questioning minds.

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