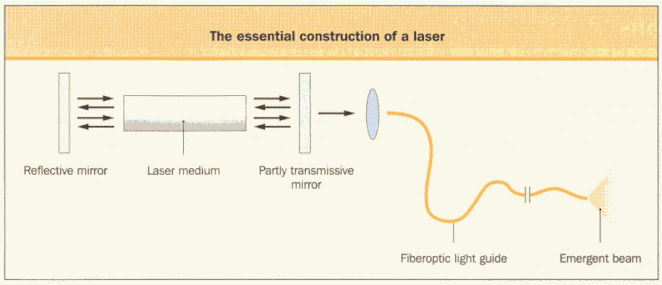
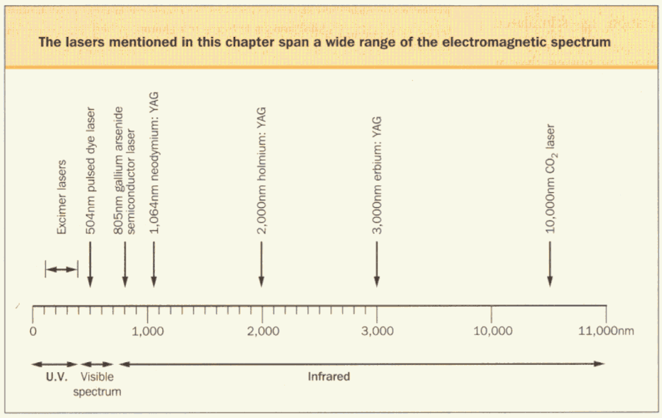
Lasers and lithotripsy

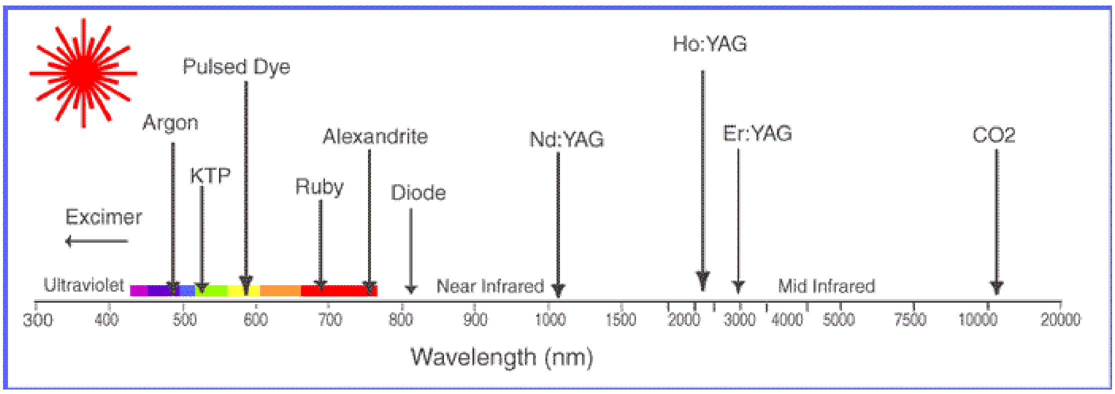
Lasers

Light amplification by stimulated emission of radiation
Lasers utilise energy (pumping) to get most electrons into a high energy state (population inversion). Change from high energy to lower electron energy state results in loss of a photon of light (emission).
Lasers (MCC)

- Monochromatic (depends on source material)
- Collimated (parallel, thus high energy density)
- Coherent (same wavelength)







Effects on tissue

- Thermal injury
  - Photothermal
    - Direct heating by energy absorption
    - Depending on temperature of tissue, coagulation (>42 degrees), ablation (>100 degrees) or vaporisation (>300

degrees) e.g. Holmium works by vaporisation of stone

Photomechanical

Very high power density – rapid heating and formation of plasma bubble. Collapse leads microjet formation and fissuring of stone as for ESWL e.g. pulsed dye laser

Non-thermal

Photochemical

Absorbed energy directly converted into chemical reactions (i.e PDT)

Effects on tissue dependent on:

- Wavelength
- Tissue absorption
- Pulse duration
- Power density
- Lasering technique

(i) Tissue penetration depends on wavelength

Pulsed dye	540nm	Deepest
HeliumNeon	630nm	
Nd:YAG	1060nm	
Ho:YAG	2140nm	
Erbium:YAG	3000nm	
CO_2	10600nm	Shallowest (~50um)

Depth of penetration inversely proportional to wavelength

Depth of penetration of holmium laser 0.5mm

(ii) Absorption characteristics

Dependent on laser wavelength each tissue has an absorption co-efficient

Colour of tissue plays an important role

Haemoglobin (red) absorbs blue-green light.

Therefore argon used to treat port-wine stains

Green light laser used for TURP – utilises Nd:YAG laser and frequency doubling crystal to generate the green light wavelength (KTP low power 80W; lithium borate high power 120W)

(iii) Pulse duration

Lasers may be continuous or pulsed

Continuous laser on for > 0.25s

Strength of continuous lasers = energy per second

Energy per second (power) = energy (J) x frequency (Hz)

Most lasers pulsed – beam switched on and off, each pulse < 0.25s

Strength on pulsed lasers = energy per emitted pulse (energy x frequency)

Q-switched lasers only allow a pulse (very short high energy pulse) after near-complete population inversion

(iv) Power density

Power per unit area. Depends on fibre diameter

Typical fibre diameters are 200uM, 365uM and 550uM

(v) Laser technique

Some lasers cut on contact, vaporise on near contact, and coagulate in non-contact mode (effectively reduces power density)

<u>Laser injury and legislation</u>

Main injury to skin and eye
Highest skin absorption far UV and far IR
No medically useful UV lasers; CO_2 lasers in far IR spectrum – used for skin ablation
Eye injury

Eyes absorb visible, near UV and near IR light
Near UV absorbed by aqueous humour and lens – cataracts

Visible light (400nm-700nm)	<u>retinal burn</u>
IR light 700-1400nm (Nd:YAG)	cataract, <u>retinal burn</u>
IR light 1400-3000nm (Ho:YAG)	cataract, corneal burn
IR light 3000nm-10000nm (CO_2)	corneal burn

BS EN 60825 classification 2007 classed lasers into 4 types:

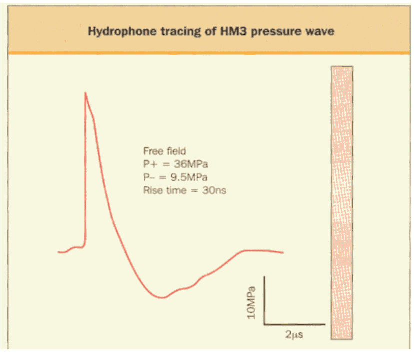
Class 1	safe
Class 2	
Class 3	
Class 4	dangerous

Most medical lasers class 3B or 4

Extracorporeal lithotripsy

Up to 85% of calculi treatable with ESWL

ESWL involves generation and transmission of shock waves onto calculi, resulting in fragmentation. Unintentional tissue damage always occurs, typically to blood vessels.



Physics and pathophysiology of SW:

Initial positive then negative pressure
Passes through stone in ~10us
Effects directly due to shockwave itself or through cavitation
Direct = Anterior and posterior fragmentation, shear and spalling
Cavitation = requires fluid medium. Negative pressure causes dissolved gas in fluid around stone to expand into bubble. Collapse of bubbles cause microjets which pit the surface of the stone (and damage surrounding tissues)

<u>ESWL machines</u>

Original ESWL machine Dornier HM3 (spark gap generated under water; GA; water bath). Now three differing mechanisms for generation of shock wave

NB. Our machine is an Siemens Lithostar (EMG) / Storz modulith SLK (EMG)

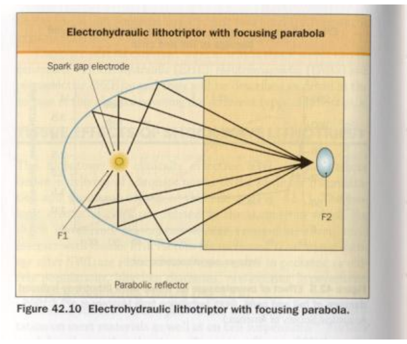


Figure 42.10 Electrohydraulic lithotriptor with focusing parabola.

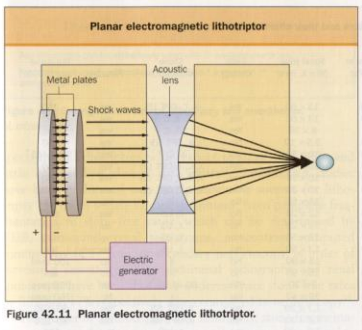
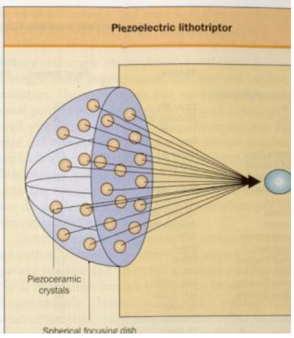


Figure 42.11 Planar electromagnetic lithotriptor.



All ESWL machines comprise 4 components:

- (i) Shock wave generator
  - Electrohydraulic
  - Electromagnetic
  - Piezoelectric
- (ii) Focussing device
  - Parabolic mirror
  - Acoustic lens
  - Focussing dish
- (iii) Coupling mechanism
  - Water bath (Dornier HM3)
  - Water or gel-filled pads
- (iv) Imaging system
  - Image intensifier
  - Ultrasound

First generation	Dornier HM3
Second generation	Non-water bath EHL machines
	EMG lithotriptors (Siemens lithostar)

Third generation	PZE lithotriptors As for second generation but portable, USS/fluoro Non-renal use, endoscopic procedures

Advantages and disadvantages of the different principles of shock wave (SW) generation

SW generation	Advantage	Disadvantage
Electrode	Wide range of energy Twin-pulse technique Flexible size of aperture (15–26 cm)	Short lifespan (3,000–4,000 SW) Renewal expensive Minimal energy necessary for discharge
Piezoelectric elements	Very long lifespan (> 1,000,000 SW) Variation of frequency (1–100 Hz) Target control	Limited range of energy Large aperture necessary (> 40 cm)
Electromagnetic elements	Wide range and continuous graduation of energy Flexible size of aperture Long lifespan (200,000–400,000 SW) Multiple focusing principles – membrane + acoustic lens – cylinder + paraboloid – spherical shape	Metal membrane must still be changed

Contraindications

- Obesity
- Coagulopathy
- UUT obstruction
- Sepsis or active UTI
- Pregnancy
- Renal artery aneurysm / AAA
- Cystine stone/monohydrate stone
- Anorexia nervosa (increased stone)
- Failure of localisation
- ? women of child-bearing age & distal ureteric stones (ovary damage)
- Splenomegaly

Efficacy based on type of machine

Table 1. Recent publications evaluating different lithotriptors for shock wave lithotripsy of renal calculi. The most contemporary series were chosen to reflect the current practices regarding lithotriptor employed, stone size, and stone location

Study	Year	Lithotriptor	Energy source	*n*	Overall stone free (%)	Retreatment rate (%)	Aux procedures (%)	Efficiency quotient
Cope *et al.* [18]	1991	Wolf Piezolith	Piezoelectric	220	75	51	4	0.48
Mykulak *et al.* [22]	1992	Therasonic	Piezoelectric	172	56	21	ND	
Cass [24]	1995	Dornier HM3	Electrohydraulic	4 796	63	6	3	0.57
Cass [24]	1995	Medstone STS	Electrohydraulic	6 195	64	6	2	0.59
Elhilali *et al.* [20]	1996	Dornier Compact	Electromagnetic	191	73	13	2	0.63
Coz *et al.* [19]	2000	Modulith SL-20	Electromagnetic	849	87	21	ND	
Lalak *et al.* [21]	2002	Dornier Compact Delta	Electromagnetic	500	63	ND	6	
Johnson *et al.* [23]	2003	Dornier Doli S	Electromagnetic	204	74	6	7	0.65

Focal volume = volume around F2 where pressure = 50% of peak
Power (energy per shock) = peak pressure (megaPa) x focal volume
Efficiency of a machine directed related to energy per shock
Pain related to energy density at skin
Explains why Dornier HM3 had highest power but GA was required
PZE machines have much higher peak pressures but focal zones low; thus pain reduced but retreatment rates increased
NB. No evidence for benefit of EMLA cream in 2 xRCTs

Efficacy based on stone location

Ureteric stones

Proximal	85%
Middle	90%
Distal	95%

Renal stones

< 2cm	90%
2-3 cm	60%

Lower pole renal calculi*

<2cm	33%
>2cm	20%

* depends on infundibular length, width, and infundibulopelvic angle

Horseshoe kidney 55% (safer vs. PCNL but retreatment rate high)

Efficacy based on stone composition

Reduced with the following stones

- Cystine
- Calcium oxalate monohydrate
- Calcium hydrogen phosphate dihydrate (brushite)

Until recently no evidence that HU alone can predict response to ESWL. Recent evidence suggests that when body mass taken into account (Skin to stone distance) may predict response (<900 and <9cm ~ 90% stone-free rate)

Efficacy based of shock-wave frequency

2 studies: between 70 and 90 shocks/min best

ESWL failure

- Stones > 15 mm
- Impacted
- Hard stones
- Unfavourable anatomy
- Failure after 2 treatments
- Localisation difficulties (mid-ureteric stones)

Complications

Early

- Renal colic
- Haematuria*
- Perirenal haematoma (?Page kidney)
- Infection
- Arrythmia

Late

- Renal dysfunction?
- Hypertension?
- Impaired fertility?

*Risk factors for renal injury:

- Age > 60
- Child

Pre-existing hypertension
Pre-existing renal impairment

(i) Infection after ESWL

Overall sepsis seen in ~1% of cases and 3% staghorn calculi
Use of prophylactic antibiotics controversial
2 x RCTs showed no benefit for patients without positive UTI or infection stones. Pearle metaanalysis 2007 however showed reduced UTI rate and reduced hospitalisation in patients receiving prophylactic antibiotics at the time of ESWL (all patients negative MSU pre-Rx)
Current recommendations for prophylactic antibiotics

- Infection stones
- Positive UTI
- History of recurrent UTI
- Instrumentation at time of ESWL
- EUA recommends Abx for 4 days afterwards

(ii) Arrythmia

Occurs in 11-59%
No increased risk of cardiac morbidity however
PPM should be checked and atrial sensing turned off (single chamber ventricular pacemakers should be fine)

(iii) Long-term renal dysfunction after ESWL

Animal studies, acute phase response and short term decrease in GFR, RPF and UO portend long-term renal damage.
Short-term effects disappear after ~7 days
Little conclusive evidence however. Janetschek et al (J Urol 1997) – increased RRI in patients with risk factors associated with new onset hypertension in 45% patients > 60 years
8% rate of new-onset hypertension after ESWL vs. 6% population
However patients with renal stones also overweight, and renal stones themselves a/w risk of hypertension

Advances in ESWL

- Better prognostication of success
    - Artificial neural networks
    - HU and skin-to-stone distance
- Adjuvant PDI therapy
- Dual shock wave machines
- Low shock-wave frequency (60 vs. 120)
- Progressive voltage increase
- Simultaneous chemolysis

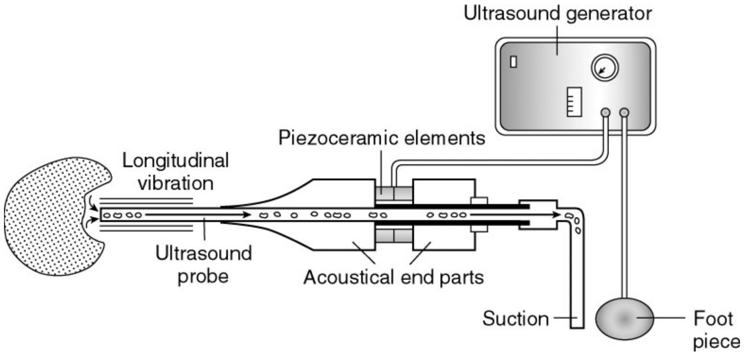
Intracorporeal lithotripsy

	Fragmentation	Safety	Stone removal	Cost
EHL	+++	+	0	+
US	++	+++	++++	+
Impact	++++	++++	0	+
Pulsed-Dye	++	+++	0	++++
Holmium	++++	++	++	+++

(i) EHL

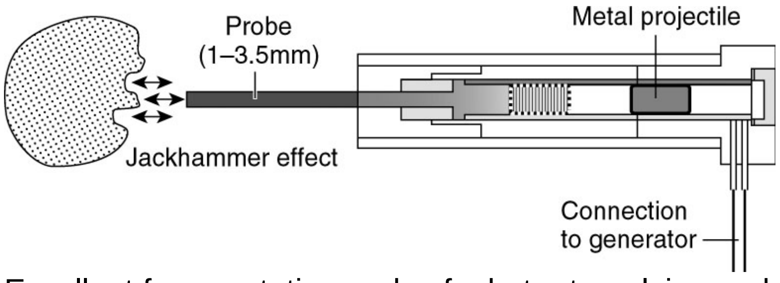
Underwater spark plug
Plasma cavitation bubble – collapse leads to microjet and fissuring
Probe just off stone (1mm)
Ureteric damage and retropulsion problematic

(ii) USS



Energy from piezoelectric crystal transmited longitudinally
Suctionallows stone removal but inefficient for hard stones

(iii) Ballistic



Excellent fragmentation and safe, but retropulsion problematic

In general holmium laser most valuable. Although ballistic methods (Swiss lithoclast) cheap, reliable and safe, associated with significant retropulsion

Semi-rigid ureteroscopy
A/w high stone-free rates
Day case procedure

>95% single treatment
Complications
- bleeding (<1%)
- infection (2%)
- extravasation (3.7%)
- perforation (1.6%)
- stricture (<1%)
- streinstrasse (<1%)
- avulsion
- instrument damage

Technical considerations
- The migrated stone
  - Push-bang
  - Push-perc
- The Impacted stone/stricture/urinary diversion
  - Percutaneous ureterolithotomy (antegrade approach: need flexible cystoscope/ FURS. If planning to use a FURS, advance 14F access sheath)
  - Laparoscopic ureterolithotomy

Flexible ureterorenoscopy

Manufacturing company	Model	Working length (cm)	Deflection up/down (degrees)	Tip diameter (F)	Proximal diameter (F)	Channel diameter (F)	Special features
Gyrus ACMI	DUR-D	65	250/250	8.7	9.3	3.6	Digital video ureteroscope; lightweight (1.18 lbs)
Gyrus ACMI	DUR-8E	64	170/180	6.75	10.1	3.6	Active secondary deflection of 130° gives total downward deflection of 310°
Olympus	URF-P5	70	275/275	5.4F	8.4	3.6	Beveled "Evolution tip"; built-in moiré-effect reduction filter
Storz	Flex-X2	67.5	270/270	7.0	8.5	3.6	Laser resistant tip (Laserite)
Stryker	FlexVision U-500	64	275/275	6.9	—	3.6	Locking mechanism during secondary deflection; high density fiber optic bundles for enhanced image resolution
Wolf	Viper	68	270/270	6.0	8.8	3.6	Slightly beveled, atraumatic small tip

Instrument channel 3.6F across board. Flow rates:

Empty channel	40 ml/min
2.2F basket	10 ml/min
3 F basket	4 ml/min

Cost and durability
- Expensive. Accounting for purchase cost, disposables and repairs, approximately 700 pounds per case. Expect 6-15 uses before repair
- Most sensitive part deflection unit
- ACMI DUR-8 (Now Storz) most reliable scope (Monga 2006)
- Damage prevention
  - Laser fibre in straight!
  - Avoid overtight coiling
  - Dedicated theatre table

Avoid back-feeding stiff wires
Lasering camera tip – dedicated laser bung

Pre-stenting a possibility to avoid PUJ stricturing. Some units (Norwich) pre-stent under local anaesthetic and USS/radiological screening
Pre-operative imaging should be mandatory (KUB on day, CT for radiolucent stones)
Unless a good anaesthetic reason, patient should be paralysed.
Access sheaths (12F or 14F; 28cm, 35cm or 46cm)

- Maintains low intrarenal pressure while operating
- Facilitates multiple entries/exits
- Protects instrument
- Passive egress of fragments
- ?Improved stone-free rates (Aude 2004)

Cook N-gage excellent for moving stones around kidney

Guidewires and JJ stents

What are the indications for stent insertion? 'SPOILED'

- Solitary anatomical or functional kidney
- Perforation or suspected perforation
- Oedema
- Infection
- Large volume residual fragments
- Secondary elective procedure planned
- Dilatation >10F

What makes a perfect stent?

- Biocompatible
- Resists migration
- Good tensile strength
- Durable
- Easy insertion
- Inhibits biofilm
- Resists encrustation
- Radio-opaque
- Cheap

Perfect material not been found:

- Silicone
  - Biocompatible and resists encrustation but insertion difficult due to high friction and low tensile strength (snaps easily)
- Polyurethane
  - Strong and easily inserted but causes mucosal ulceration
- Polyethylene
  - Biocompatible, but durability poor and crusts
- Copolymers
  - Best combination. May be based on silicone (c flex or silitek) or other
  - Percuflex stents (Boston Scientific) **olefinicblock co-polymer strong and low friction but encrusts**

Animal studies have shown that JJ stents a/w:

- Dilated ureter
- Impaired peristalsis
- Impaired stone passage

Does a stent relieve obstruction?
Controversial
Urine refluxes up the centre of a stent
Urine drains alongside stent
JJ stent in an unobstructed ureter results in a rise in renal pelvic pressure
JJ stents require significant pressure to drain compared with nephrostomy
Does a stent impair stone passage?
Controversial
One meta-analysis (Abdel-Khalek 2003) of 938 pts shown that stone free rates after ESWL slightly lower in stented rather than non-stented patients
AUA guidelines – stents do not improve outcome in patients with ESWL May actually impair outcome

How bad are stent symptoms?
Ureteric stent symptom questionnnaire (Joshi 2002)

- 78% had bothersome LUTS
- >80% pain
- 32% sexual dysfunction
- 58% reduced work capacity

No difference between standard stent, polaris, long loop, short loop (Lingeman 2005)
No difference in stent size, but 4.8F stents appear to migrate more
Reduced pain and readmission rate with overnight ureteric catheter vs. stent

<u>Guidewires</u>
4 main types

- PTFE coated steel core
  - Standard wire
  - Cheap £5
  - Low friction, reasonably stiff, but can kink
- Hydrophilic
  - Slippery and stiff
  - Mid-range £11
  - Migration problematic
- Hybrid wires
  - Sensor g/w
  - Hydrophilic tip, stiff nitinol core body
  - Difficult cases
  - Expensive £30
- Super stiff
  - Kink resistant
  - Mid-range