UltrasoundWaves in StoneFragmentation

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Advanced Techniques in Kidney Stone Treatment

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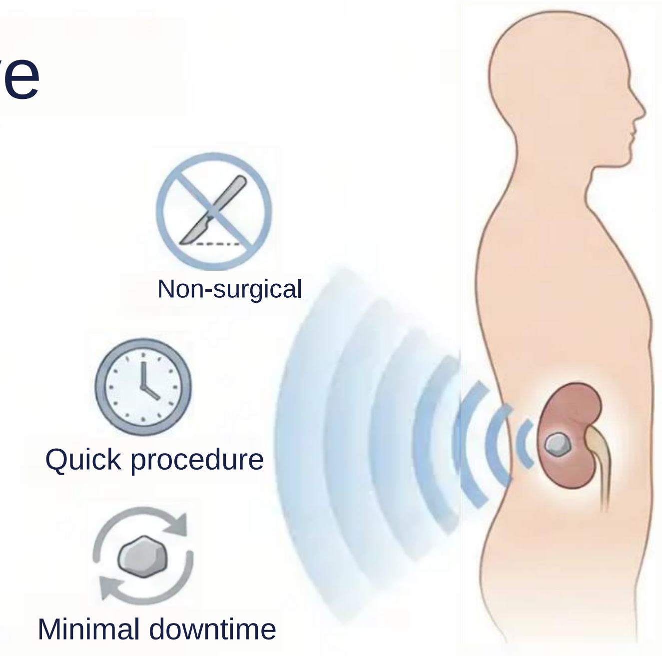
Introduction to Lithotripsy

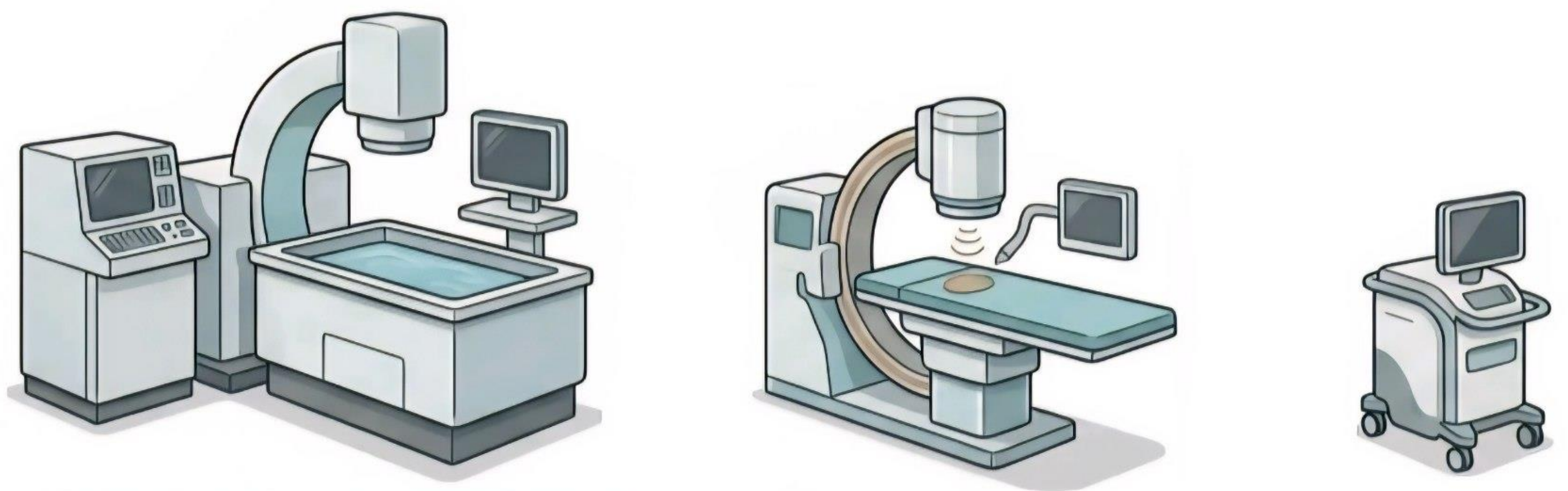
Lithotripsy is a non-invasive or minimally invasive procedure used to treat kidney stones too large to pass naturally by using focused ultrasonic energy or shock waves.



- Non-invasive treatment option
- Alternative to surgical removal
- Uses focused energy waves
- Breaks large stones into passable fragments

Revolutionary approach that eliminates the need for open surgery in most kidney stone cases

Evolution of Lithotripsy Technology



Key Innovation

The shift from water baths to 'dry' therapy heads revolutionized patient care, eliminating immersion requirements and enabling outpatient procedures.

1980s

First Generation

- Electrohydraulic systems (Dornier HM3)
- Patient immersion in water baths
- Large, stationary equipment
- Electrode-based shock wave generation

1990s

Second Generation

- Electromagnetic lithotriptors
- Water-filled therapy heads ('dry' systems)
- Improved patient comfort and mobility
- Reduced equipment footprint

2000s

Third Generation

- Piezoelectric technology
- Integrated imaging guidance
- Portable and mobile units
- Enhanced targeting precision

Physics of Ultrasound in Medicine

Dual Role of Ultrasound Technology

- **Diagnostic Imaging**
  - High-frequency sound waves create detailed internal images
  - Real-time visualization of kidney stones and anatomy
  - Non-invasive stone detection and positioning
- **Therapeutic Fragmentation**
  - Mechanical energy delivery through focused transducers
  - Contact probes provide direct stone destruction
  - Controlled energy transfer minimizes tissue damage

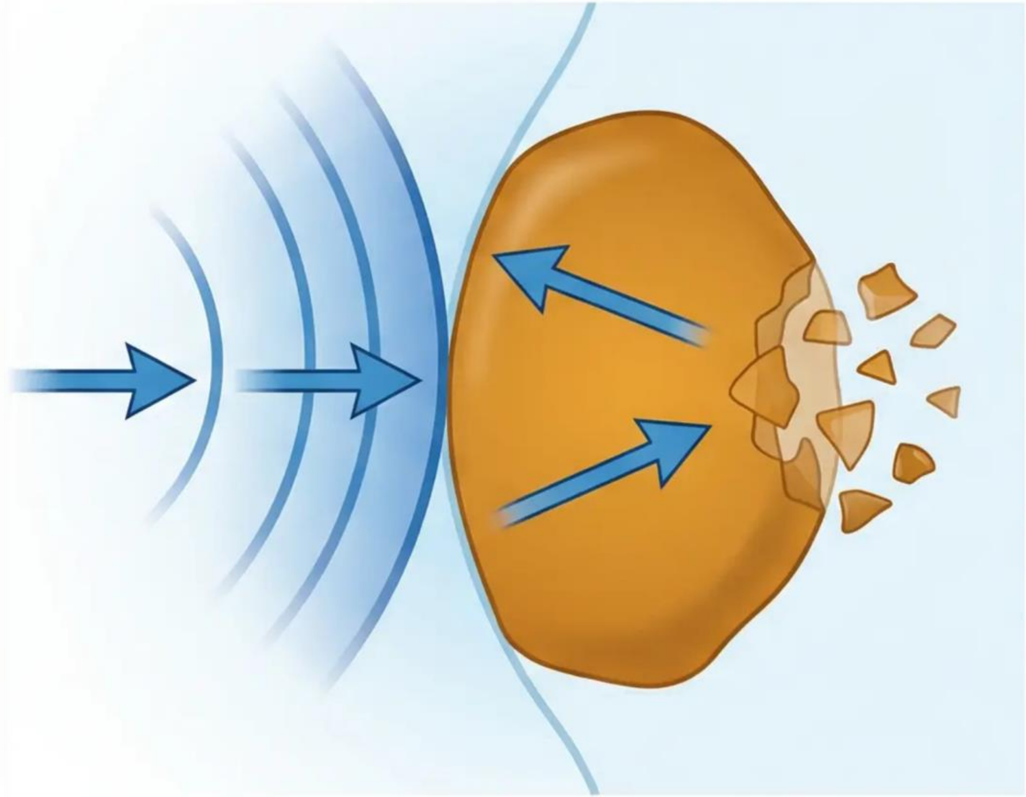
Key Physics Principle

Sound waves convert electrical energy into mechanical vibrations at frequencies of 23-25 kHz, creating precise therapeutic effects while remaining safe for surrounding tissues.

Fragmentation Mechanism: Spalling

Spalling occurs when shock waves reflect at the stone-water interface, causing a phase inversion that creates tensile stress, splitting material off the rear of the stone.

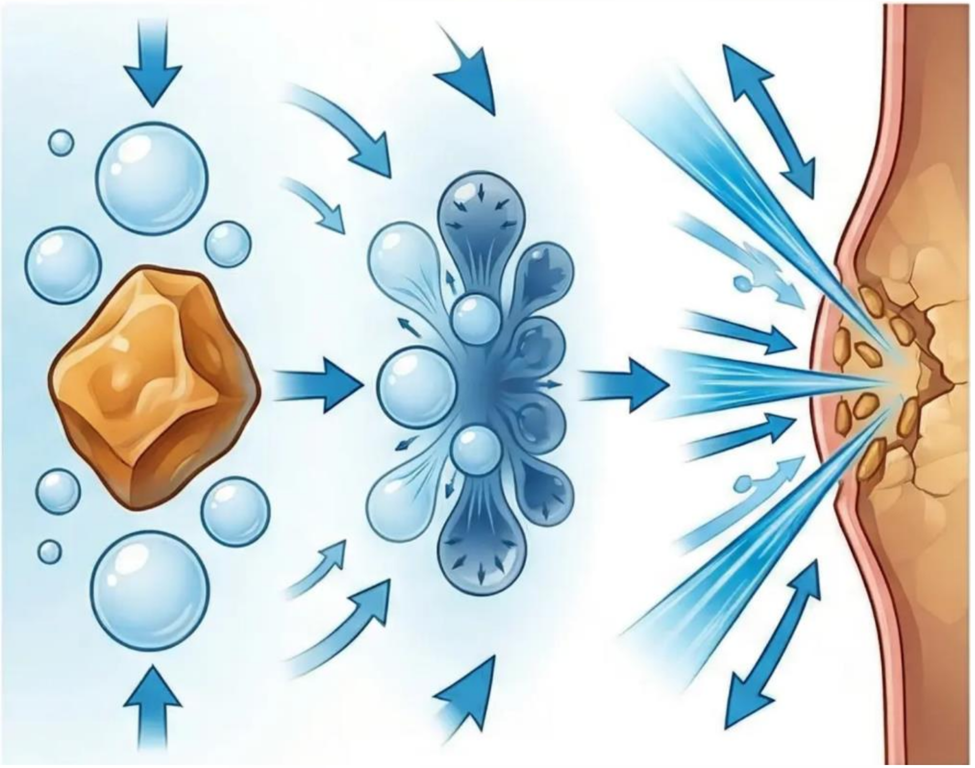
- Shock wave travels through water medium
- Wave encounters stone-water interface
- Phase inversion creates reflection
- Tensile stress develops at rear surface
- Material fragments separate from stone



Fragmentation Mechanism: Cavitation

• Negative pressure phases create gas bubbles in surrounding fluid
• Bubbles undergo rapid, violent collapse
• Collapse generates powerful microjets

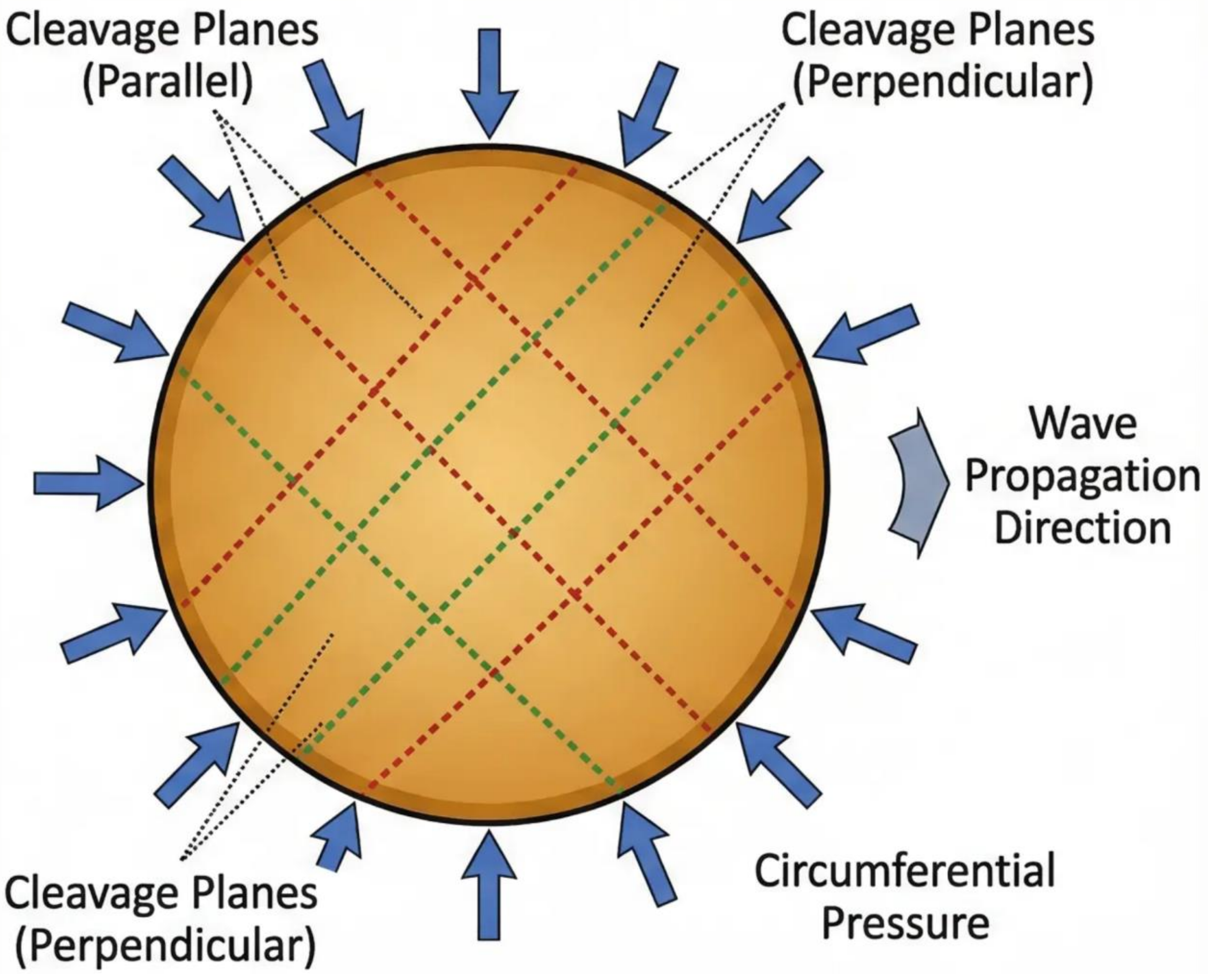
• Secondary shockwaves erode stone surface
• Cumulative erosion leads to fragmentation



Cavitation bubbles can reach temperatures of 5,000K and pressures exceeding 1,000 atmospheres during collapse

Fragmentation Mechanism: Squeezing

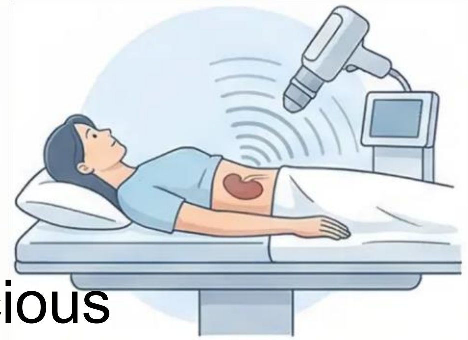
• quasi-static circumferential pressure applied to stone surface
• generates internal tensile stress within the stone structure
• creates cleavage planes in two possible orientations:
• parallel to wave propagation direction, and
• perpendicular to wave propagation direction
• mechanism depends on stone composition and internal structure



Comparing ESWL and Ultrasonic Lithotripsy

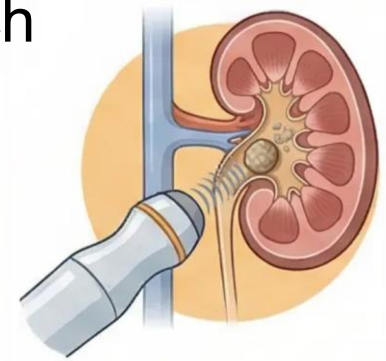
Extracorporeal Shock Wave Lithotripsy (ESWL)

- Completely non-invasive procedure
- External shock wave application
- Best for small stones (less than 2cm)
- Patient remains conscious
- Outpatient treatment option
- Lower procedural complexity



Ultrasonic Lithotripsy

- More invasive approach
- Direct contact with stone required
- Highly effective for larger stones
- Superior performance on harder stones
- Requires surgical access
- Precise fragmentation control



Future Trends: Burst Wave Lithotripsy (BWL)

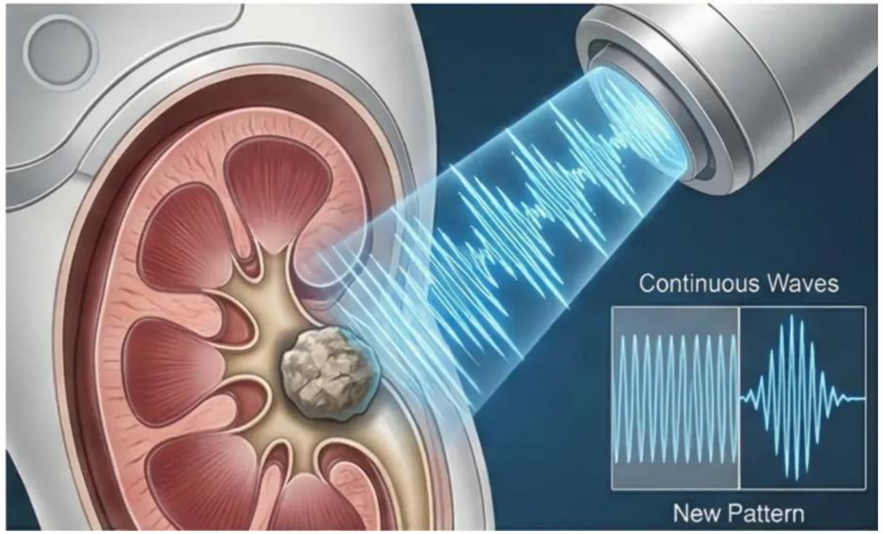
Key Innovation Points

• Short, focused ultrasound bursts replace continuous waves

• Operates at significantly lower pressures than ESWL

• Maintains high fragmentation efficiency

• Reduces potential tissue injury risk



BWL represents the next generation of stone treatment – combining precision targeting with enhanced patient safety

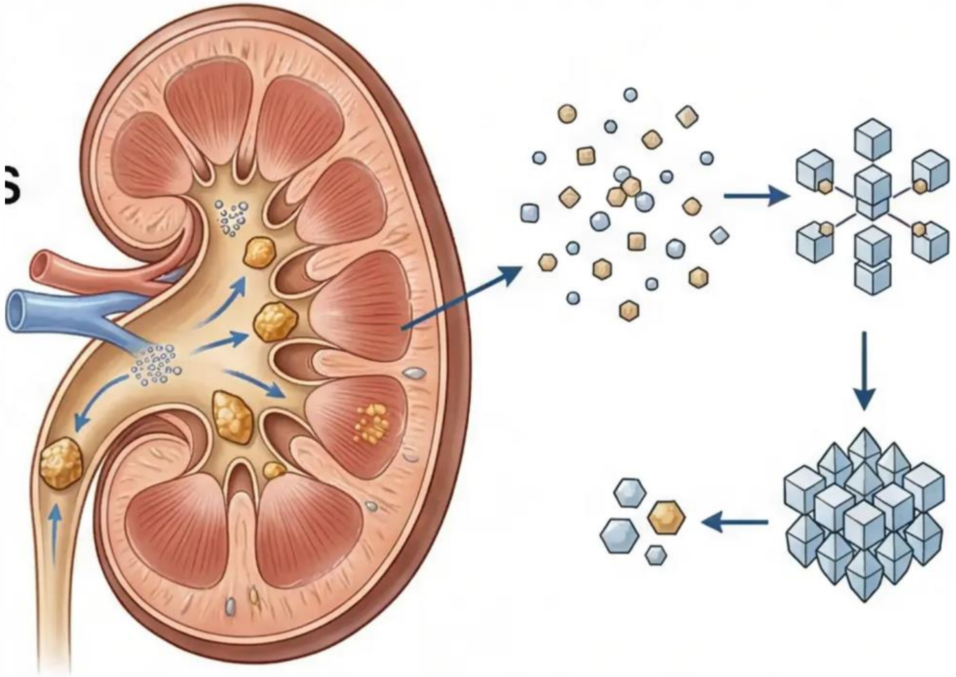
Understanding Kidney Stone Formation

Kidney stones develop through a process of crystallization when certain substances become concentrated in urine and begin to precipitate out of solution.

Common Stone Types:
- Calcium Oxalate (80%)
- Calcium Phosphate (15%)
- Uric Acid (5%)
- Struvite & Cystine (Rare)

Key Formation Process:

- **Supersaturation - Urine becomes oversaturated with stone-forming substances**
- **Nucleation - Crystal formation begins around a nucleus**
- **Growth - Crystals aggregate and grow larger over time**
- **Retention - Stones may become lodged in the urinary tract**

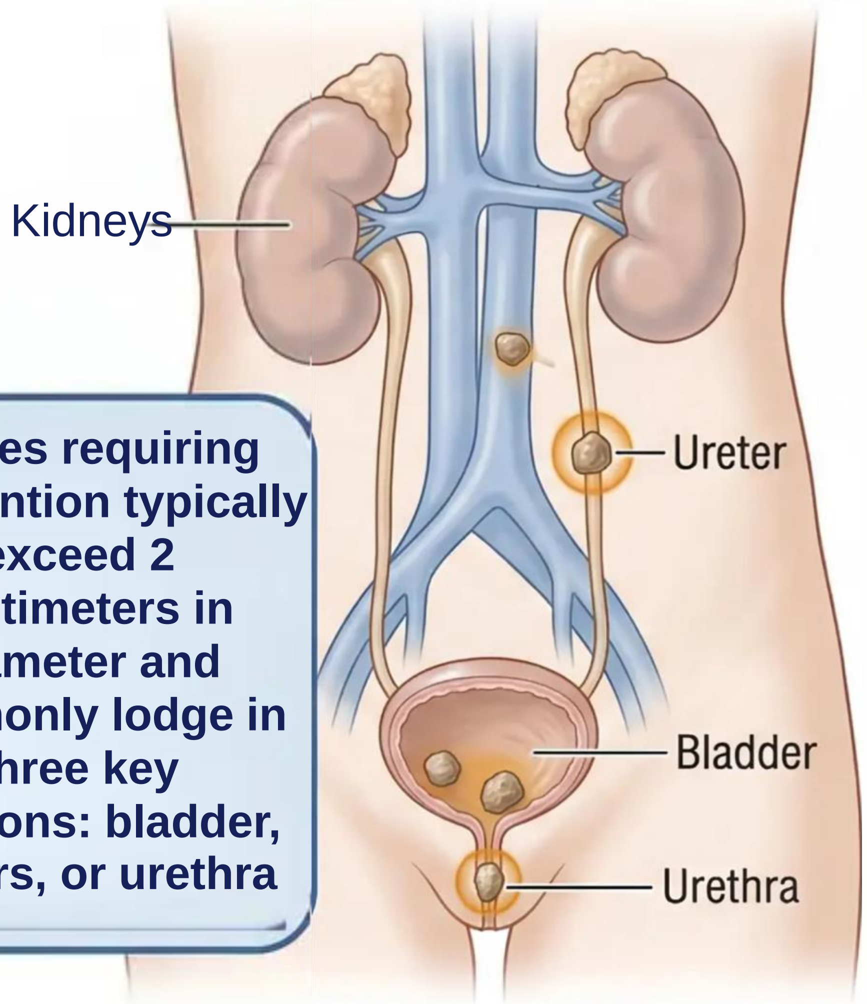


The Human Urinary System

The urinary system serves as the body's filtration mechanism, removing urea and maintaining essential chemical balance throughout the body.

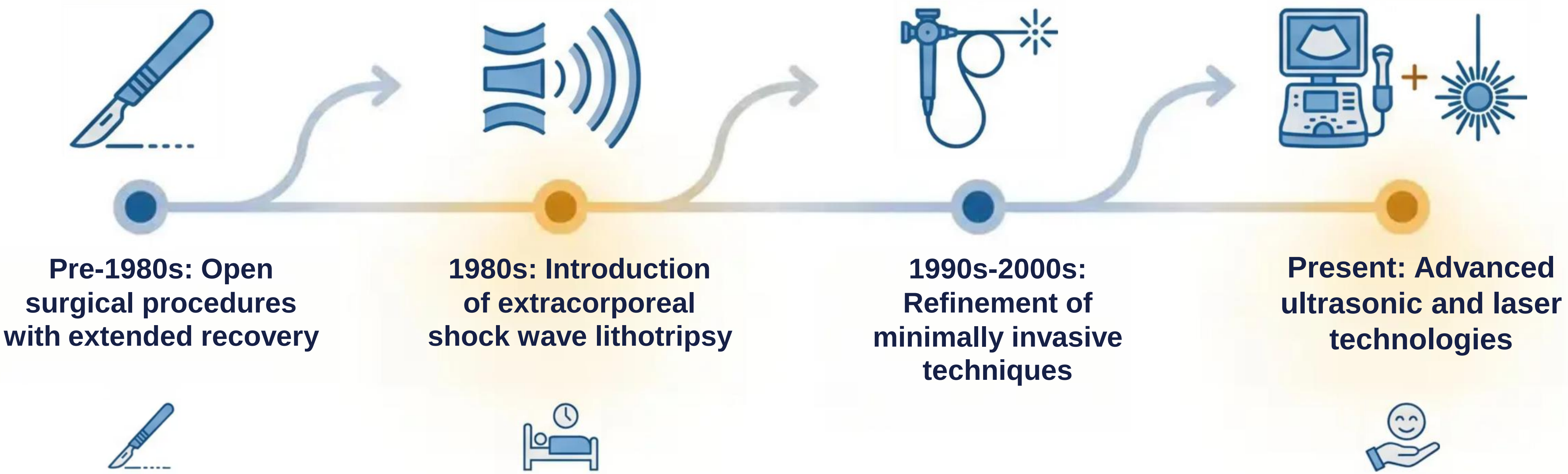
- Filters waste products from blood
- Regulates fluid and electrolyte balance
- Maintains acid-base homeostasis

Stones requiring intervention typically exceed 2 centimeters in diameter and commonly lodge in three key locations: bladder, ureters, or urethra



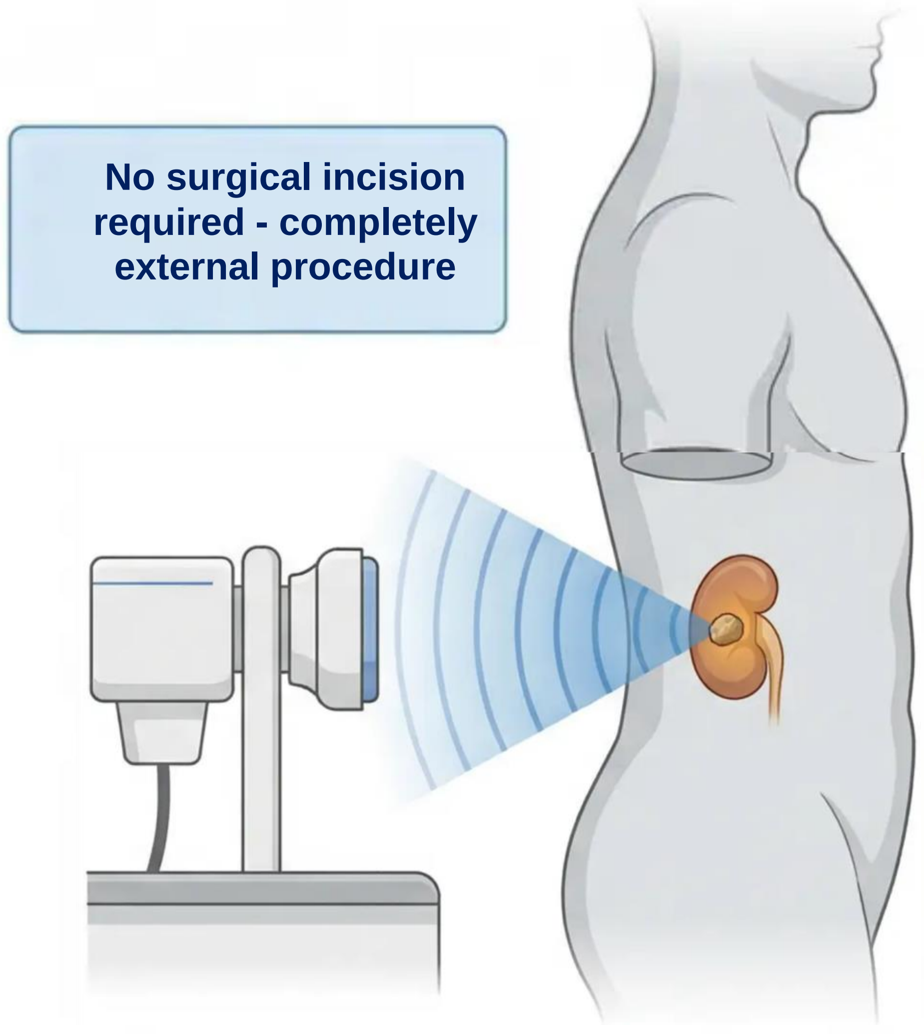
Evolution of Stone Treatment

Since the 1980s, lithotripsy has revolutionized urology by allowing stone removal without major surgery, significantly reducing recovery times and surgical risks for patients.



Extracorporeal Shock Wave Lithotripsy (ESWL)

- Non-invasive treatment approach
- Shock waves generated outside the body
- Waves travel harmlessly through soft tissue
- Precisely targeted at kidney stones
- Fragments stones into passable pieces
- Eliminated naturally through urine

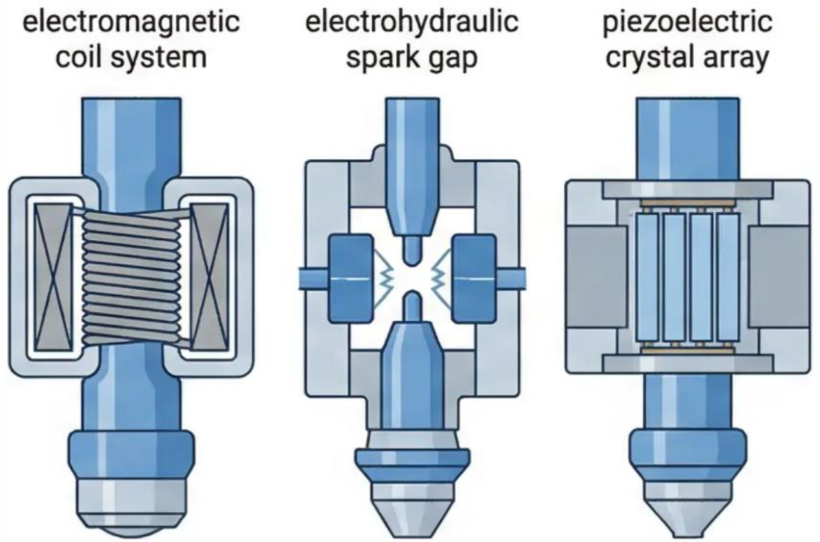


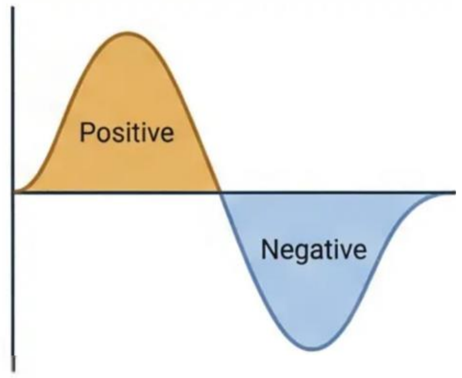
Shock Wave Generation Methods

Three Generation Methods:

- **Electromagnetic**
  - Uses magnetic coil system to generate rapid pressure changes
  - Provides precise control over wave characteristics
  - Most commonly used in modern systems
- **Electrohydraulic**
  - Creates shock waves through underwater spark discharge
  - Original lithotripsy technology
  - Generates high-energy pulses
- **Piezoelectric**
  - Employs ceramic crystals that expand when electrically stimulated
  - Offers excellent focusing capabilities
  - Produces consistent wave patterns

Each method produces pressure pulses with a distinctive biphasic pattern - an initial high-pressure positive phase that compresses tissue, followed by a negative tensile phase that creates cavitation effects.





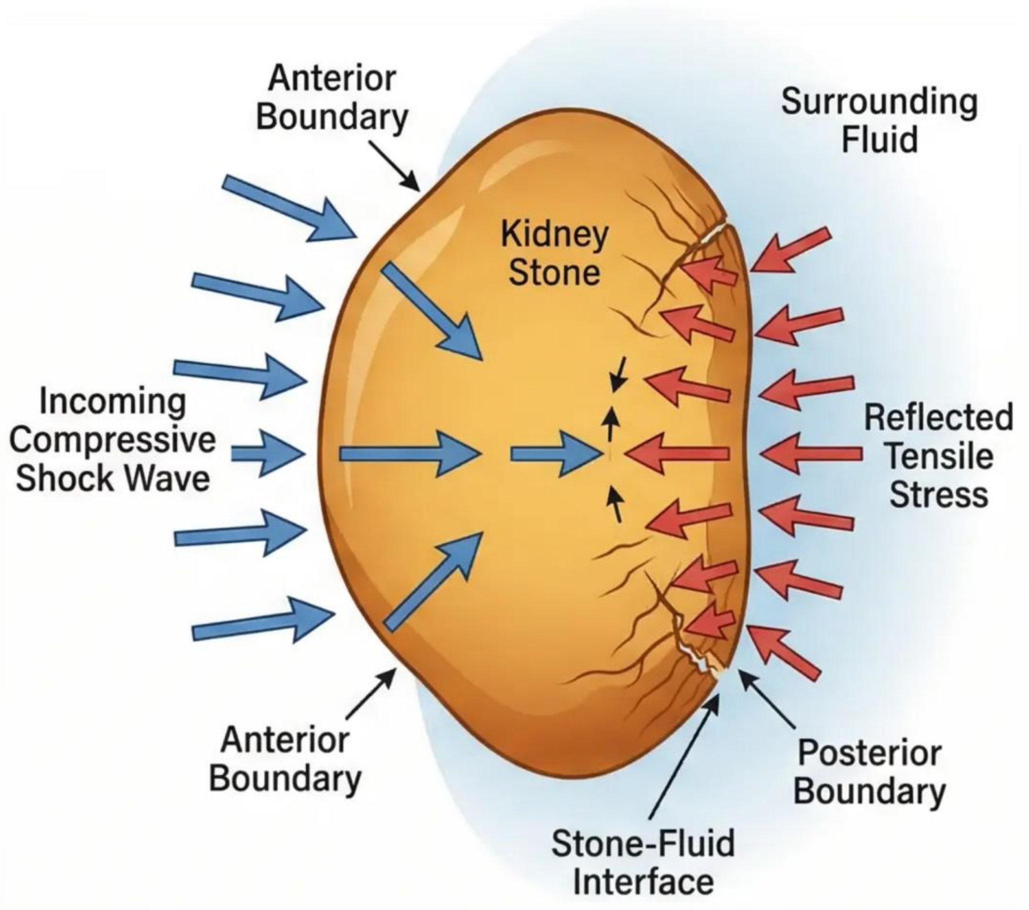
The Hopkinson Effect

- **Definition: A phenomenon where tensile stress develops at the posterior boundary of a kidney stone during shock wave impact**

- **Mechanism: Compressive waves reflect as tensile waves at the stone-fluid interface**

- **Clinical Significance: Primary driver of stone fragmentation in traditional shock wave lithotripsy**

- **Location: Occurs specifically at the back surface of the stone where it meets surrounding fluid**

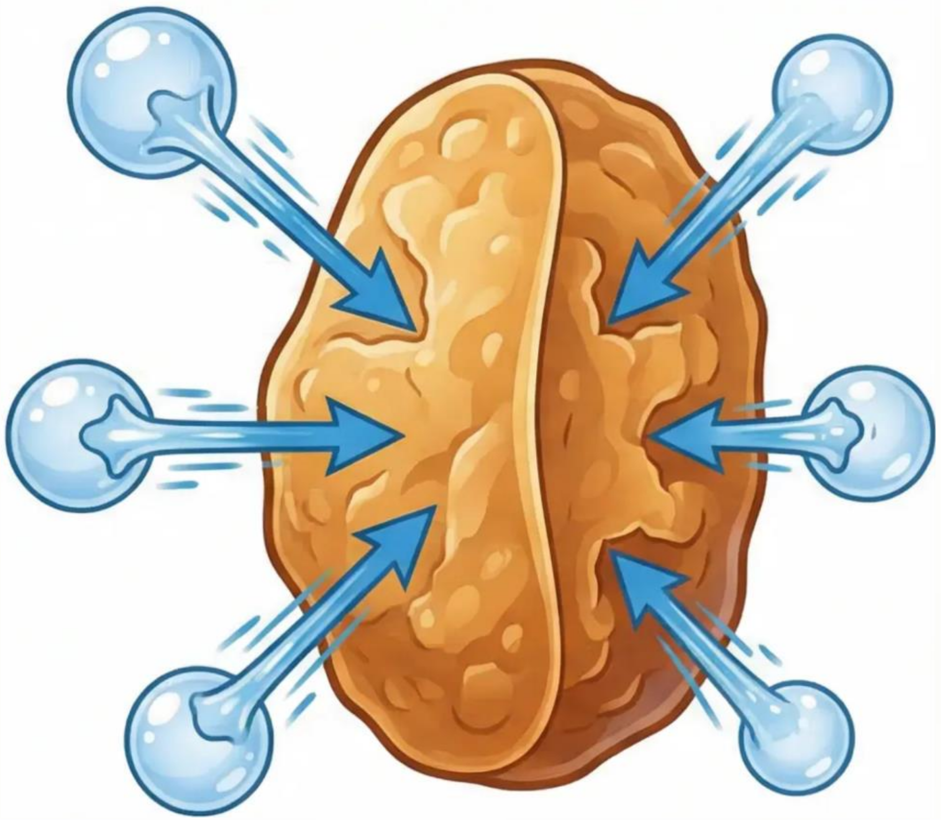


Role of Cavitation Microjets

Microjets produced during bubble collapse act as a contributory mechanism for renal calculi disintegration, especially effective at the anterior and posterior surfaces of the stone.

- High-velocity water jets form when cavitation bubbles collapse asymmetrically
- Most effective at stone surfaces facing the ultrasound source
- Secondary mechanism complementing primary acoustic pressure
- Enhanced erosion at stone edges and irregular surfaces

Microjet velocities can reach up to 100 m/s during bubble collapse, creating localized high-pressure impacts

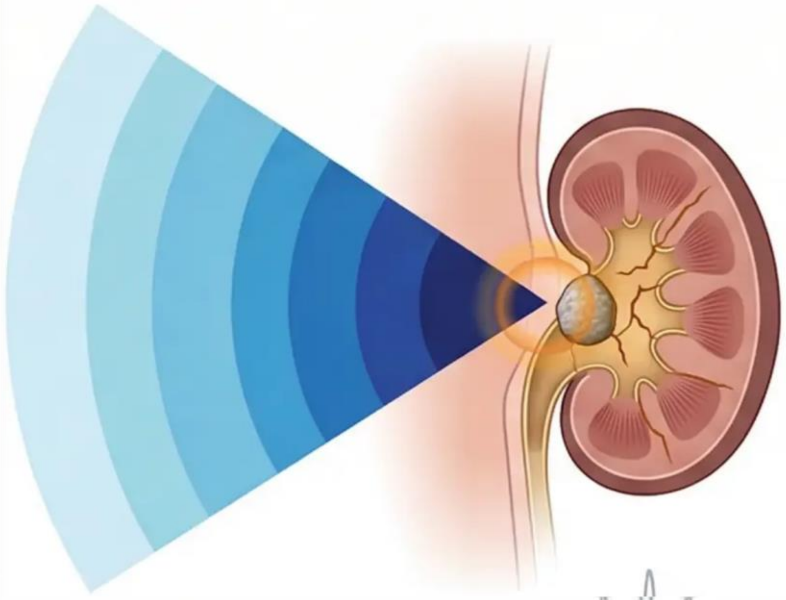


Pressure Wave Characteristics

- **Key Physical Parameters:**
  - Peak Pressure Range - Optimal range: 10-40 MPa for effective stone fragmentation
  - Pulse Duration - Short, controlled bursts maximize energy transfer efficiency
  - Focal Dimensions - Precise focusing concentrates energy at the stone location
  - Parameter Balance - Success requires careful optimization of all three factors

Clinical Insight

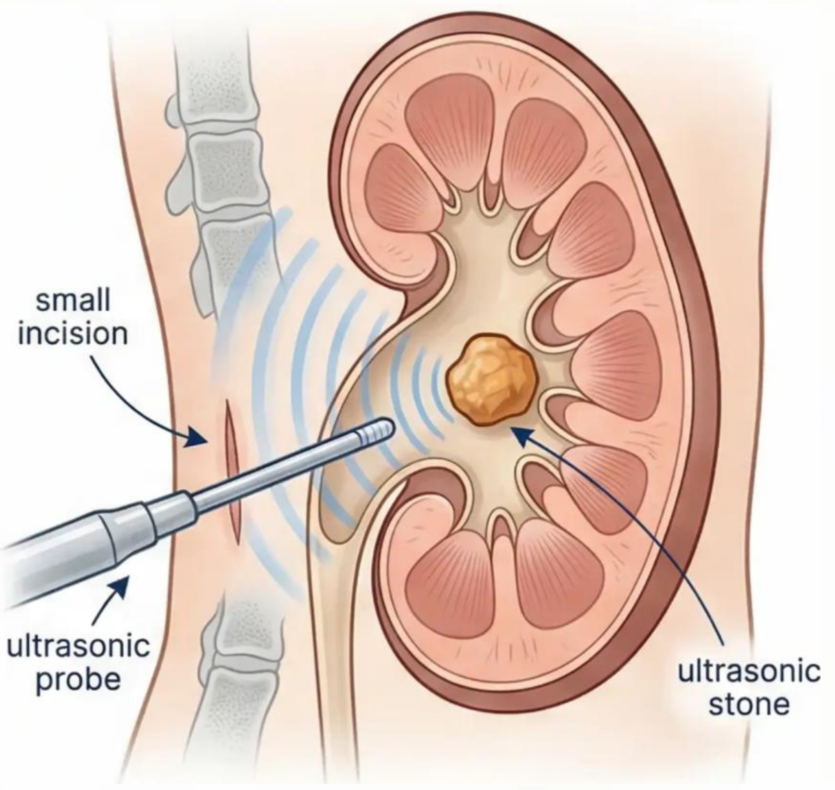
“Fragmentation efficiency increases exponentially when all three parameters are properly balanced rather than maximizing any single factor”



Ultrasonic Lithotripsy in PCNL

In Percutaneous Nephrolithotomy (PCNL), an ultrasonic probe is inserted directly through a small incision to fragment large stones via high-frequency mechanical vibrations.

- Direct contact fragmentation method
- Minimally invasive surgical approach
- Effective for large kidney stones
- High-frequency mechanical vibrations
- Precise stone targeting capability



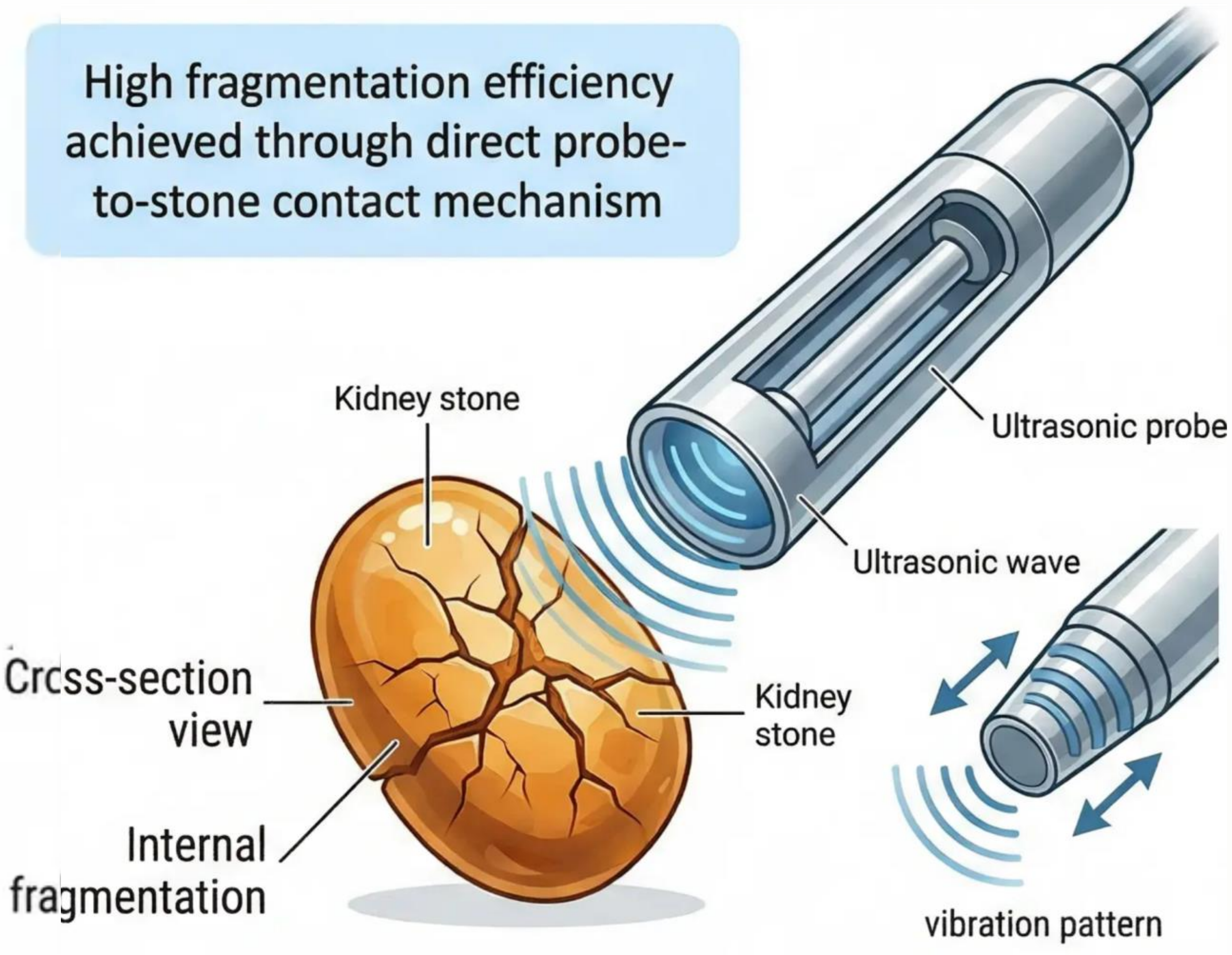
Contact Ultrasonic Probes

• Key Mechanism: Direct contact vibrations at high frequency

• Pressure Range: 10-40 MPa ultrasonic energy delivery

• Target Application: Hard and large calculi fragmentation

• Advantage: Maximum transfer through direct contact

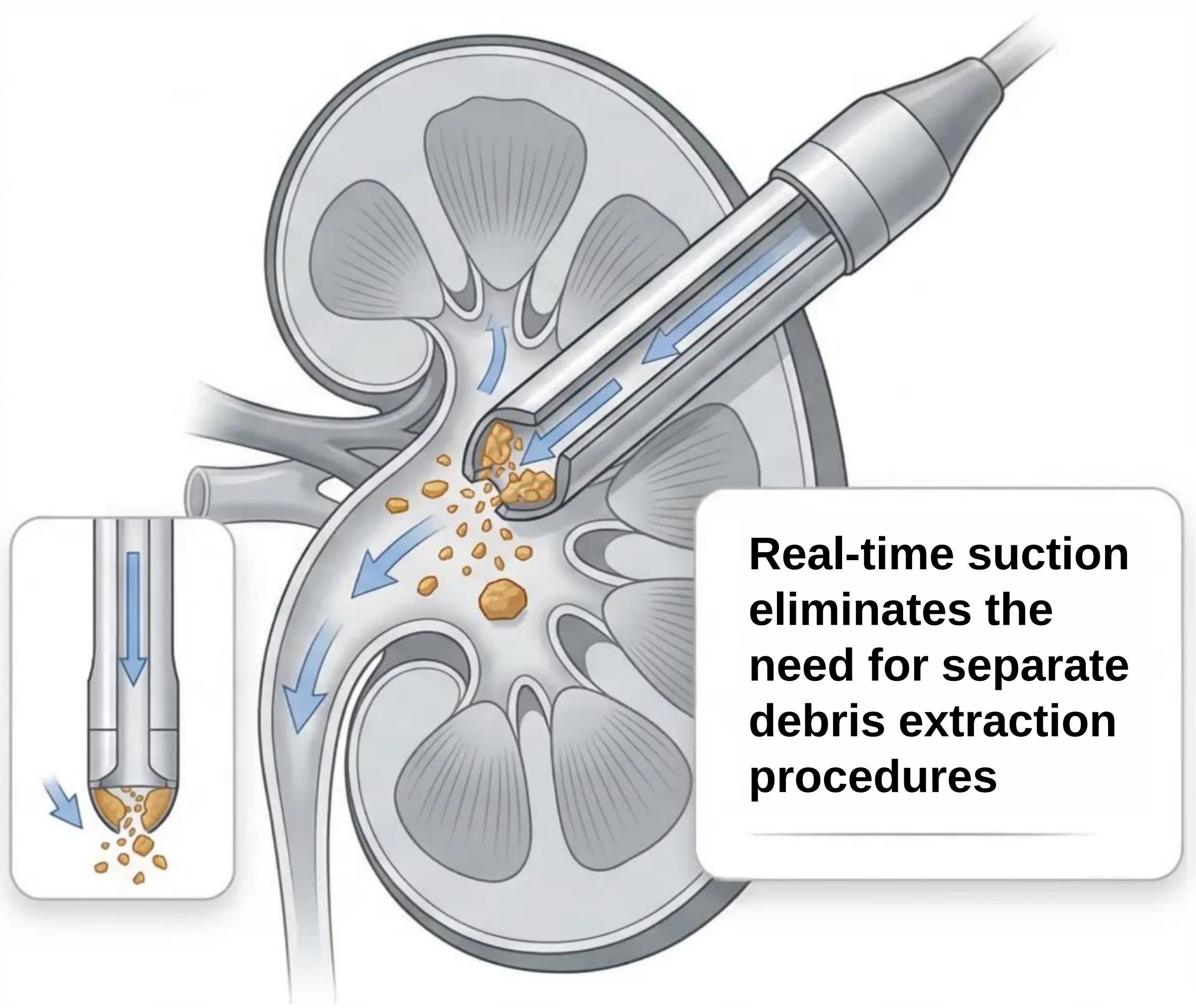


Simultaneous Suction Mechanism

A key advantage of ultrasonic probes in PCNL is the ability to simultaneously suck out stone debris, reducing the risk of residual fragments and ureteral blockage.

Key Benefits:

- Immediate debris removal during fragmentation
- Prevents fragment migration
- Reduces procedure time
- Minimizes post-operative complications



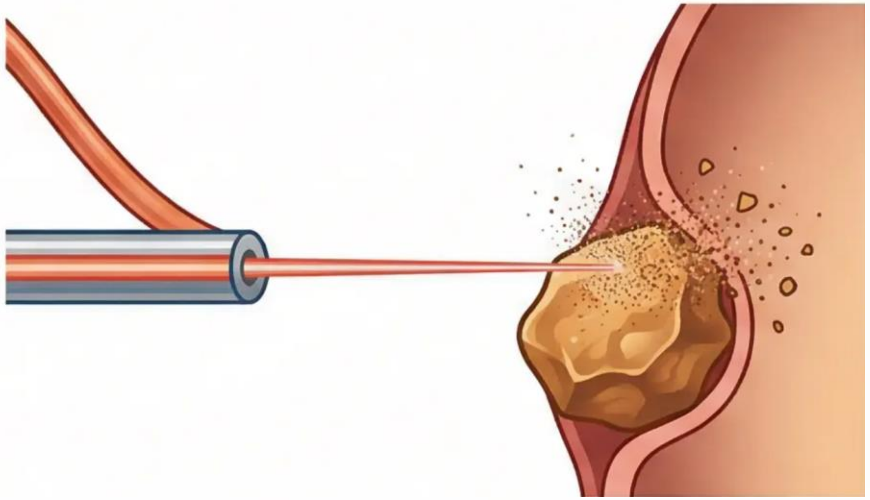
Ultrasound vs. Laser Lithotripsy

Ultrasound Technique

- Mechanical vibration mechanism
- Physical contact with stone required
- Integrated suction system
- Preferred for very large stones
- Simultaneous fragmentation and removal

Laser Technique

- Holmium:YAG fiber technology
- ‘Dusting’ approach to stones
- Precise energy delivery
- Effective for various stone types
- Minimal mechanical contact



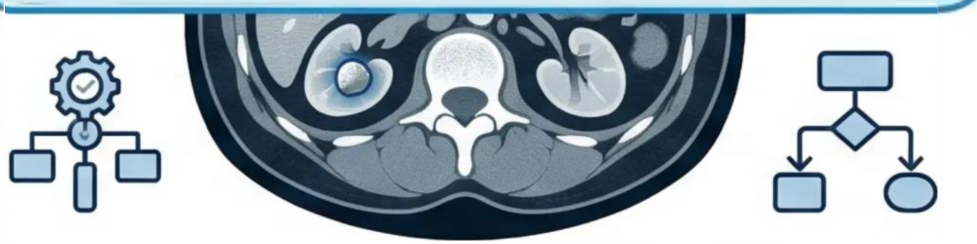
Clinical Procedure: Patient Preparation

Pre-Treatment Assessment Protocol

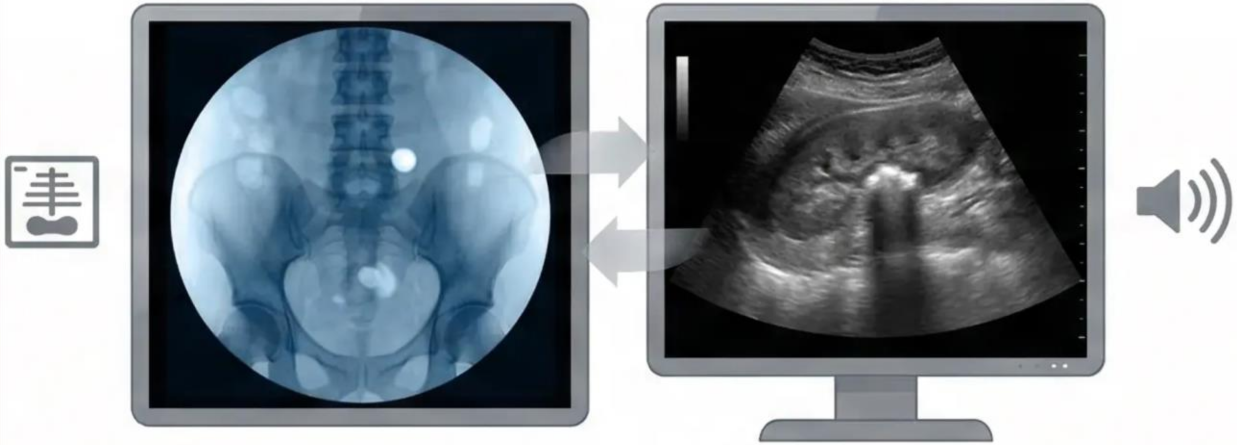
- CT Imaging Evaluation
  - High-resolution computed tomography scan
  - Stone location and size measurement
  - Anatomical pathway assessment
- Hounsfield Unit Analysis
  - Stone density measurement in HU values
  - Soft stones: Less than 500 HU
  - Hard stones: Greater than 1000 HU
- Treatment Decision Matrix
  - ESWL suitable for softer stones
  - Surgical intervention for dense stones
  - Patient anatomy considerations

Critical Threshold

Hounsfield units above 1000 HU typically indicate stones requiring surgical intervention rather than shock wave therapy



Imaging Guidance Systems



Fluoroscopy (X-ray) Guidance

- Real-time X-ray imaging
- Precise stone localization
- Continuous procedure monitoring
- Excellent for radiopaque stones

Pelvic Ultrasound Guidance

- Non-ionizing radiation approach
- Soft tissue visualization
- Real-time fragmentation assessment
- Complementary stone detection

Dual Imaging Benefits

Enhanced accuracy through combined modalities for optimal treatment outcomes

Factors Influencing Success

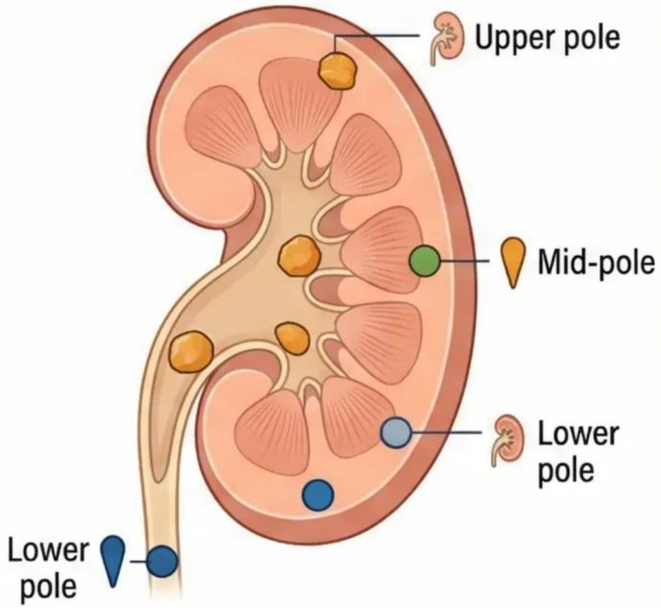
Three critical determinants shape treatment outcomes and guide clinical decision-making in ultrasonic lithotripsy procedures.

Stone Size

- Smaller stones: Higher clearance rates
- Larger stones: May require multiple sessions
- Size threshold affects technique selection

Anatomical Location

- Lower pole stones: More challenging clearance
- Ureteropelvic junction: Optimal access
- Calyceal anatomy impacts fragment passage



Stone Composition

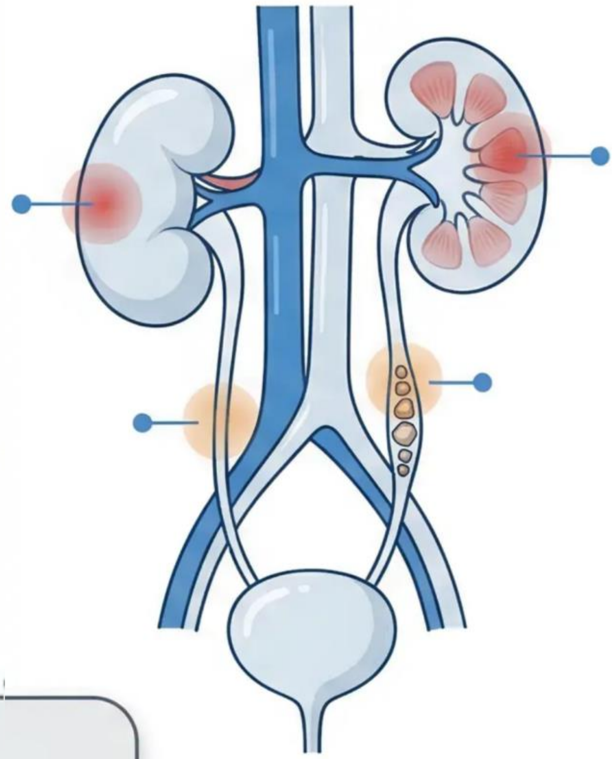
- Calcium oxalate: Most responsive to ultrasound
- Uric acid stones: Excellent fragmentation rates
- Cystine stones: More resistant, require longer treatment

Treatment success depends on matching the appropriate technique to stone characteristics and patient anatomy

Risks and Complications

Understanding Potential Adverse Effects

- Primary Risk Categories:
  - Hematuria - Blood in urine following procedure
  - Tissue Bruising - Localized tissue damage at treatment site
  - Infection Risk - Post-procedural urinary tract infections
  - Steinstrasse Formation - Ureter blockage from stone fragment chain

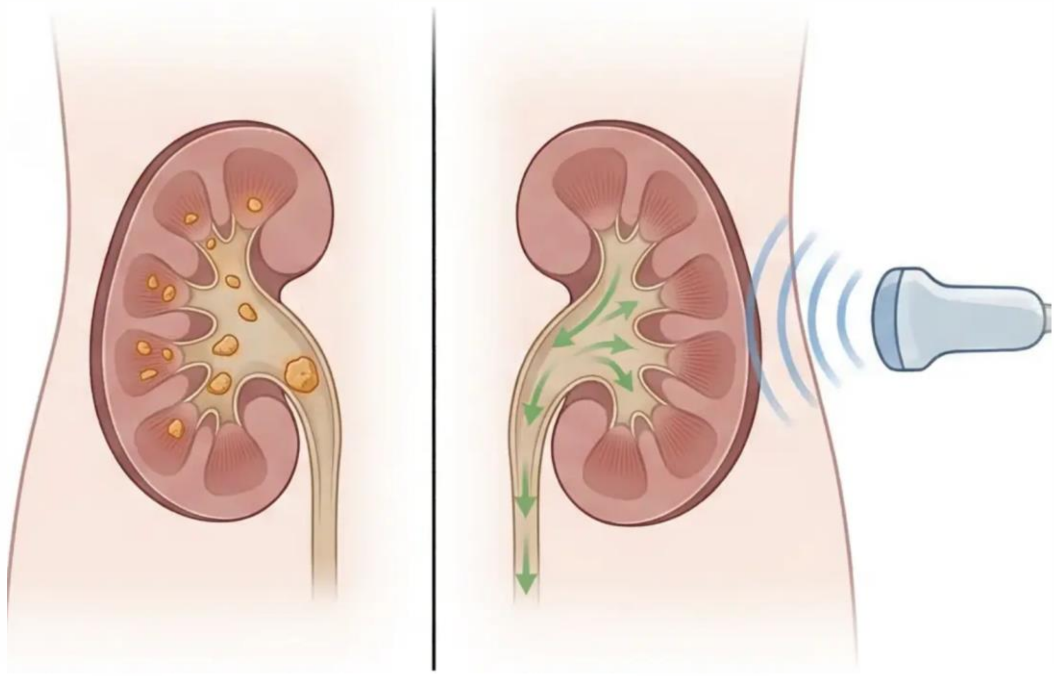


Steinstrasse: “Stone Street”

A serious complication where multiple stone fragments create a chain-like blockage in the ureter, potentially requiring additional intervention

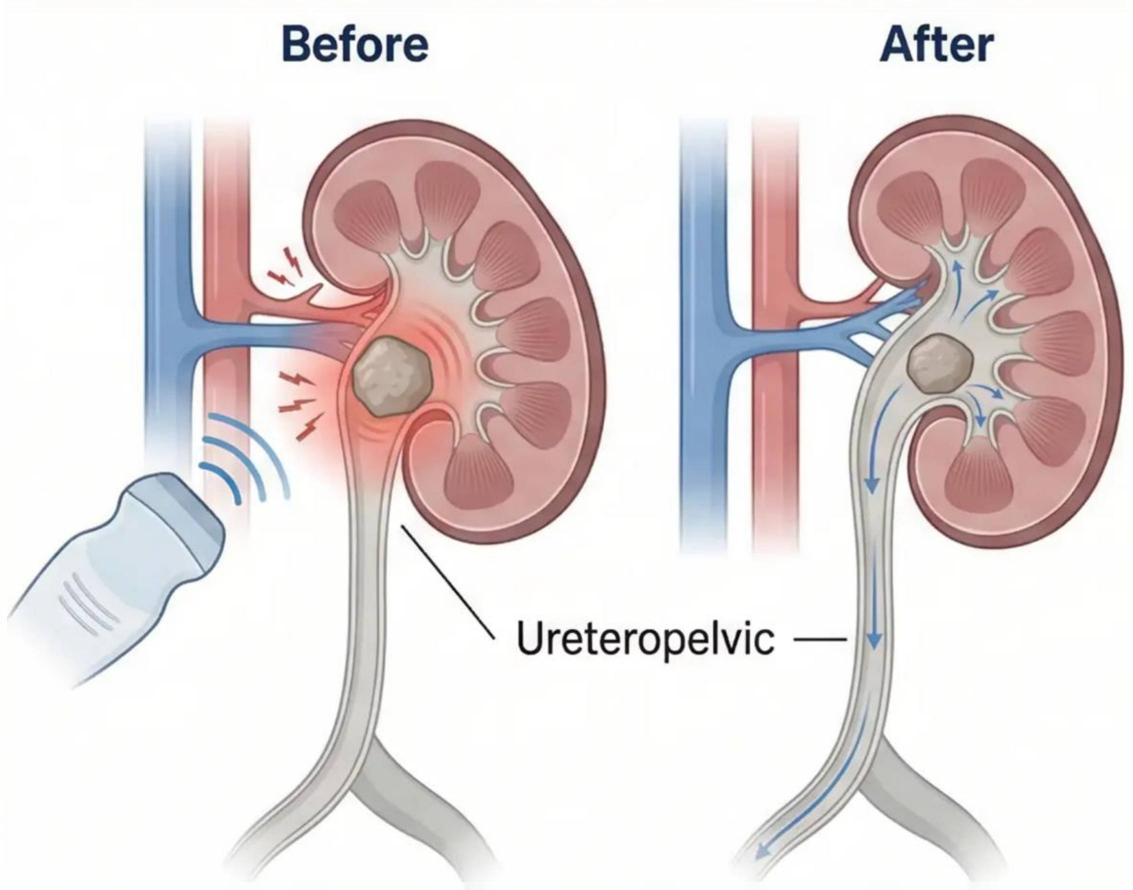
Case Study 1: Post-Lithotripsy Fragment Clearance

- **Patient Background**
  - Post-SWL patient with persistent residual fragments
  - Fragments retained for several weeks without natural passage
  - Patient experiencing ongoing discomfort
- **Ultrasound Propulsion (UP) Treatment**
  - Non-invasive outpatient procedure
  - Targeted ultrasound waves applied externally
  - Treatment duration: Single session
- **Clinical Outcome**
  - Successful clearance of over 30 small stone fragments
  - Immediate relief reported by patient
  - No adverse effects observed



Within hours of UP treatment, the patient reported passage of multiple small fragments — a dramatic improvement after weeks of retention.

Case Study 2: Acute Pain Relief via Repositioning



Case Overview

A patient presented with a large stone at the Ureteropelvic Junction (UPJ) causing severe obstruction and intense pain.

Clinical Scenario

- Initial Presentation: Stone lodged at UPJ causing severe pain
- Pain Level Before Treatment: Level 5 (severe)
- Intervention: Ultrasound Propulsion (UP) repositioning
- Outcome: Immediate pain reduction to Level 3

Immediate Pain Relief: 40% reduction in pain intensity through non-invasive stone repositioning

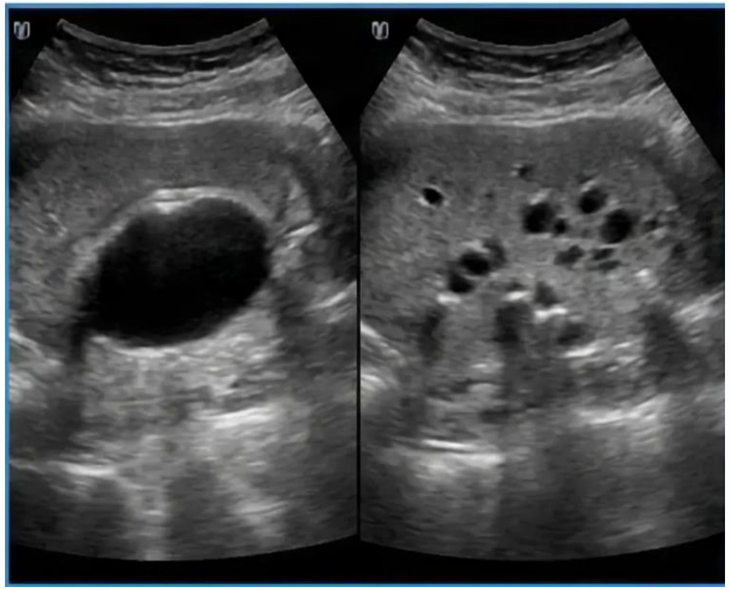
Case Study 3: Diagnostic Differentiation of Stone Clusters

Clinical Scenario:

- Four patients presented with apparent single large stones on B-mode imaging
- Standard ultrasound suggested surgical intervention for large stone removal
- Treatment plans initially focused on complex extraction procedures

Ultrasound Propulsion Revelation:

- Application of UP technology revealed true nature of formations
- “Single stones” were actually clusters of small fragments
- Discovery completely altered surgical approach and patient management



Diagnostic Accuracy:
UP technology provides superior stone characterization compared to standard B-mode imaging alone

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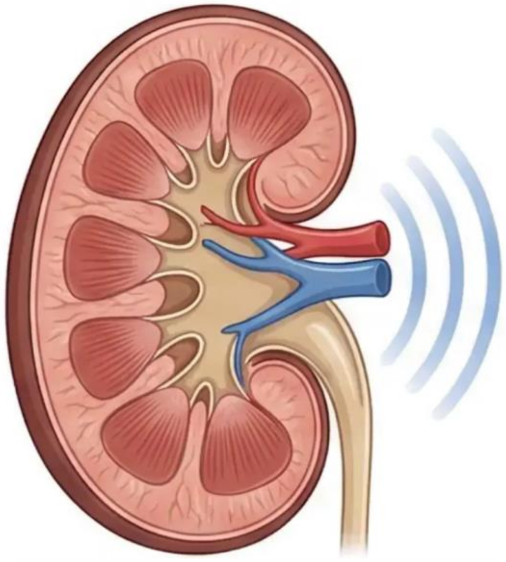
This diagnostic capability enables more accurate treatment planning and reduces unnecessary invasive procedures

SLIDE 28: CASE STUDY

Case Study 4: Safety and Tissue Injury Comparison

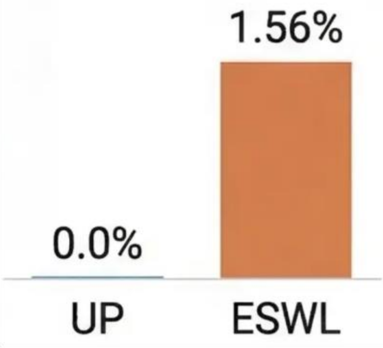
Clinical trials demonstrate significant safety advantages of Ultrasound Propulsion over traditional methods



Ultrasound Propulsion (UP)

- **0.0% tissue injury at clinical settings**

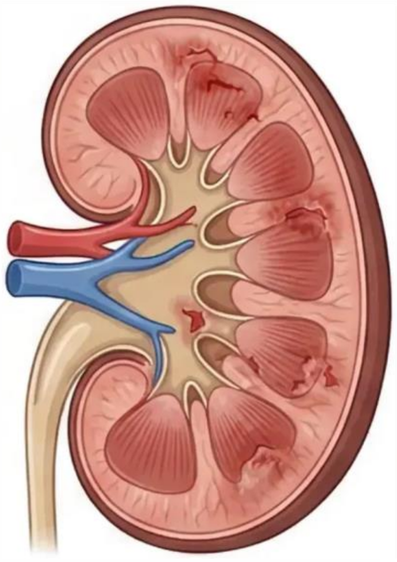
- • Study Parameters: Controlled clinical trial conditions with standardized protocols



ESWL Treatment

- **1.56% injury volume recorded**

- • Study Parameters: Controlled clinical trial conditions with standardized protocols



Clinical Implications

- UP shows superior safety profile for patient care
- Reduced risk of secondary complications
- Enhanced treatment confidence for practitioners

Case Study 5: Enhanced Fragmentation with Combined UP

Research Finding: Combining Burst Wave Lithotripsy (BWL) with Ultrasound Propulsion pulses significantly increased fragmentation rate

Clinical Impact: Facilitates faster stone clearance compared to BWL alone

Treatment Advantage: Synergistic effect enhances overall overall treatment efficacy