Ultrasonic Energy

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Last Updated:

Tuesday, February 14, 2023

Keywords:

Ultrasonic energy, ultrasound, shockwave lithotripsy, percutaneous lithotripsy, ultrasonic shears

1. PHYSICS/INTRODUCTION

Ultrasound is a sound wave with a frequency beyond the limits of human hearing (greater than 20,000 Hz). At a range of frequencies between 2 and 18 mHz, ultrasound is commonly used to obtain diagnostic images. Many medical specialties began to utilize ultrasonic energy at even higher frequencies (between 23 and 55 kHz) for the transmission of energy through a surgical instrument and into the body.

An ultrasound transducer probe generates and receives sound waves by means of the piezoelectric effect, which was first described in the late 1800's. As a generator delivers alternating polarity electrical current to piezoelectric quartz crystals within an ultrasound probe, there is transformation of the shape of the crystals (alternating expansion and contraction). This results in conversion of electrical energy to mechanical energy to create a linearly oscillating surface at a very high frequency (23,000 to 25,000 Hz). This vibratory surface is attached to a solid shaft ending in a probe, jaw, or blade. As a result, the probe, jaw, or blade then oscillates in a linear fashion with similar high frequency to the vibrating piezoelectric crystals.

When ultrasonic waves are applied at low power levels, there is no effect on tissue, as seen in the use of ultrasonic diagnostic imaging modalities. However, when higher sound wave amplitude and density are utilized, ultrasound energy can be employed for surgical dissection, coagulation, and destruction.

As high frequency ultrasonic waves travel through tissue, part of the energy wave is absorbed causing the intracellular ions to oscillate. This high frequency movement generates significant frictional forces and leads to temperature elevation of the cellular contents. Temperatures can exceed 65 to 95° C, resulting in cell death within a focused area, but also preserving the cells that lie nearby. If even more electromagnetic energy is delivered to the quartz crystals, the amplitude of the ultrasound waves increases, leading to mechanical disruption of cellular contents through the process of cavitation. As the focused ultrasonic waves interact with micro-bubbles of the water native to the target tissue, the bubbles oscillate violently leading to collapse of their walls, energy dispersion and mechanical destruction, supplementing the damage already caused by high temperatures. Conjointly, this vibratory stimulation also creates a zone of low atmospheric temperature, wherein the boiling point of water is decreased resulting in vaporization at lower temperatures than with other modalities, such as radiofrequency ablation.

The combination of physical pressure from a surgical instrument, with oscillation caused by ultrasonic sound waves, disrupts tissue protein hydrogen bonds in a process called coaptation. Cellular collagen molecules collapse after their proteins have been fragmented, leading them to become more adherent to one another. When physical pressure and ultrasonic sound waves are applied to tissue for a more extended period of time, the ultrasonic waves induce internal cellular friction that manifests in rising temperatures, breakdown of hydrogen bonds, and protein denaturation. A sticky coagulum is then produced, thereby sealing these tissues, which may be exploited in coagulating vessels.

2. MECHANISM OF DELIVERY

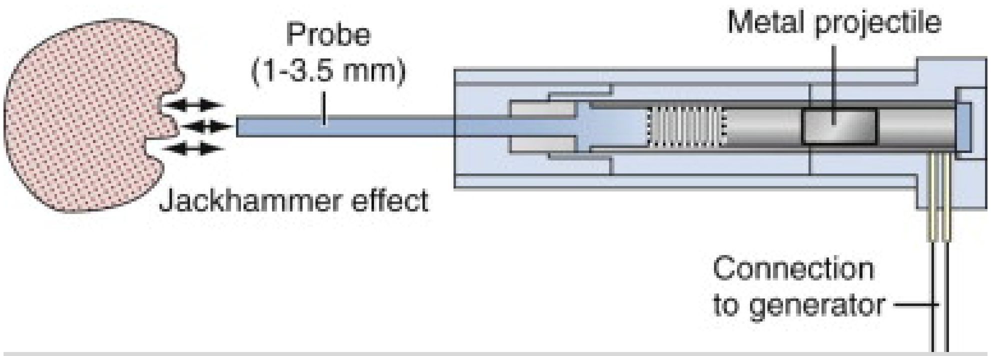

Figure 1: Ultrasonic energy from the generator is transformed through the vibration of a metal projectile within the hollow probe which then exerts this energy to the stone using direct contact.

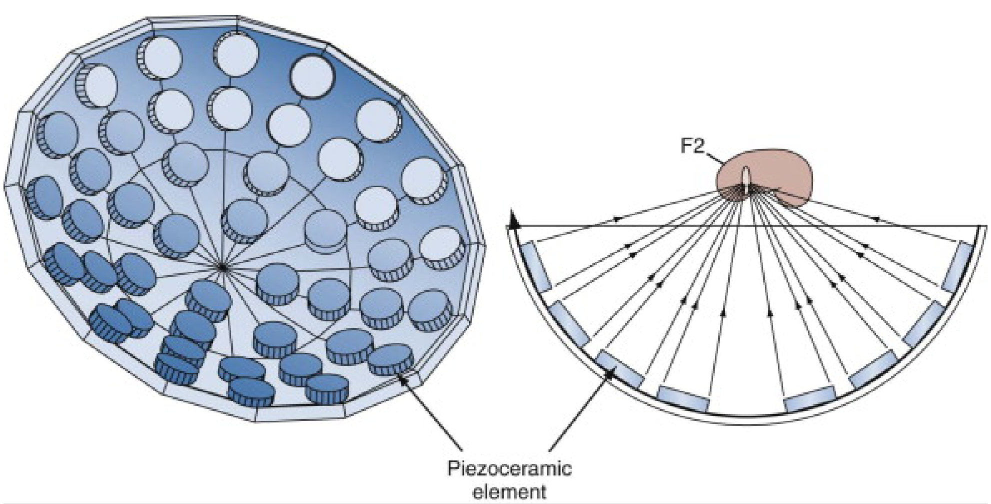

Figure 2: Piezoelectric crystals align in a spherical reflector to transmit ultrasonic energy waves through the body during extracorporeal shockwave lithotripsy.

Ultrasonic energy in urologic surgery can be harnessed in one of two ways, heat or mechanical energy.

1. Heat Energy
    a. Ultrasonic Shears:
        - A handheld ultrasonic device directly interacts with tissue and generates friction. When enough friction is generated, the tissue is heated, and cauterization occurs.

    b. High Intensity Focused Ultrasound (HIFU):
        - Ultrasonic energy is transformed into heat. The HIFU probe focuses that heat on a single point resulting in tissue destruction.
2. Mechanical Energy
    a. Percutanenous Nephrolithotripsy:
        - Ultrasonic energy is transformed into the vibration of a hollow probe, which then exerts this energy to a target (stone). The probe is put into contact with the stone, directly (**Figure 1**).

    b. Shockwave Lithotripsy:
        - Deformation and expansion of piezoelectric crystals aligned along a spherical reflector transmits ultrasonic energy waves through the body. The waves are fairly weak individually, thereby avoiding tissue injury during transmission. But when the waves converge at a focal point, such as a stone, enough force is generated to cause fragmentation during extracorporeal shock wave lithotripsy (**SWL**) (**Figures 2**).

3. SAFETY

Knowledge of the potential complications of ultrasonic energy in its various applications is paramount to maintaining a safe operating environment. Depending on the particular type of ultrasonic energy application utilized, various factors should be considered to minimize the risk of these surgeries.

In the example of ultrasonic shears, great care should be taken to ensure that the active end of the handpiece only grasps the desired tissue/structure, and not any neighboring tissues, prior to activation. A "safe zone", where no heat is externally conducted, is also a standard component of the handpiece, preventing accidental thermal injury. The patient should be positioned properly, with appropriate padding of pressure points, and then secured to the operating table to avoid any intraoperative mobility or motion, which could result in inaccurate targeting of the energy.

During SWL, precise coupling of the energy to the patient is essential to maintain a safe operating environment. Intraoperatively, the patient should be secured to the bed and anesthesia should be adequate enough to minimize or avoid movement in the stone's location. Furthermore, concordance between stone location and shock wave target zone should be verified throughout actual treatment to ensure that the ultrasonic energy is being delivered optimally to the appropriate site.

During percutaneous nephrolithotomy, it is important that the destructive application of ultrasonic energy from the lithotripter handpiece to a stone is not transmitted to nearby tissues (such as the renal parenchyma or urothelium). Fortunately, neighboring tissues do not generally resonate in response to the vibrational energy, unlike the targeted stone. The probes used during ultrasonic lithotripsy also allow for a greater flow rate of irrigation during procedures allowing one to avoid an elevated thermal effect at the tip of the probe, which improves visualization. Active suction though the probe itself allows the surgeon to maintain adequate visualization and also to evacuate small stone particles (2 mm or less) that have been fragmented.

A safety measure utilized during transrectal HIFU includes insertion of a rectal cooling probe, which is inserted at the onset of the treatment and used throughout the procedure. This cooling mechanism, along with a precisely defined position of the transducer, can minimize the risk of rectal injury. Anticoagulation medicines should be stopped 10 days prior to the procedure to avoid rectal bleeding. Rectal fistulae are contraindications to proceeding with HIFU as a poorly healed fistula may be more susceptible to injury during the procedure than healthy rectal tissue. Monitoring of the effects of HIFU can be performed with standard ultrasound as the targeted tissue area will appear hyper-echoic. That said, unfortunately the extent of ablation is not always clearly visible. More precise visualization of the target zone can be achieved using enhanced T1 weighted MRI, which can more clearly demonstrate the margins of necrotic tissue. Newer applications include MR guided transurethral HIFU.

4. DEVICES- Most commonly utilized urologic ultrasound applications

There are numerous commercially available ultrasonic generators, probes and devices available for use during urologic surgery.

Ultrasonic Shears

1. Ethicon Harmonic Synergy Blade™
2. Ethicon Harmonic Ace Shears™
3. Ethicon UltraCision Harmonic Scalpel™
4. Covidien AutoSonix™
5. Covidien Sonicision™
6. Olympus SonoSurg X™
7. Olympus Thunderbeat™ - Combination Ultrasonic and Bipolar

Ultrasonic Lithotripters for PCNL

1. Boston Scientific Swiss Lithoclast Select™ - Combination Ultrasonic and Pneumatic
2. Storz 27086C Ultrasonic Lithotripter
3. Storz 27085K Ultrasonic Lithotripter
4. Wolf 2271 Ultrasonic Lithotripter with Suction Pump

5. Wolf 2270 Ultrasonic Lithotripter
6. Wolf 2167 Ultrasonic Lithotripter
7. Olympus Cyberwand - Combination Ultrasonic and Bipolar

Ultrasonic Lithotripters for SWL

1. Storz Modulith SLX-F2
2. Storz Modulith SLX-F2-Transportable
3. Storz Modulith SLK

HIFU

1. Ablatherm™
2. Sonablate™
3. TULSA-PRO™

5. CLINICAL USE/PROCEDURES

1. Urinary calculi
   a. Ultrasonic lithotripters in PCNL and SWL
2. Benign prostate hyperplasia (BPH)
   a. HIFU
3. Prostate cancer
   a. HIFU
4. Open, laparoscopic, robotic surgery for dissection and coagulation
   a. Harmonic scalpel

6. COMPLICATIONS

Most complications from ultrasonic energy use during urologic surgery occur when tissues adjacent to the targeted site are inadvertently heated. This can result in potential destruction of non-targeted tissues such as the ureter, bowel or any other abdominal/pelvic organs, depending on the procedure being performed.

Continuous activation of an ultrasonic shear elevates tissue temperatures in excess of 200°C. The harmonic shear must cool down after application and therefore care must be taken to avoid immediate contact with nearby tissues to prevent inadvertent thermal injury.

Complications following the use of ultrasonic lithotripters are generally of minor significance. The main complications encountered are mostly those noted during percutaneous nephrolithotomy procedures, including bleeding, mucosal injury, and perforation of the collecting system with urine extravasation. Several studies have shown these complications to be adequately managed with conservative measures, such as extended placement of ureteral stent.

In the treatment of BPH and prostate cancer, patients generally have tolerated HIFU treatments well with minor complications. The most common side effect following treatment is urinary retention, as seen in approximately 20% to 28% of patients. Other reported complications include urethral stricture, urinary incontinence, urinary fistula and pain in the perineum. Some reports have suggested 27-61% develop some degree of erectile dysfunction.

Videos

Core Curriculum Ultrasonic Energy 2021 Powerpoint

Presentations

Ultrasonic Energy Presentation

References

1 Amaral J, Chrotstek C. "Experimental comparison of the Ultrasonically-activated scalpel to electrosurgery and laser surgery for laparoscopic use." Minim Invasive Ther Allied Tech: 1997: 6: 324-331

2 Cordeiro et al. "High-Intensity focused ultrasound (HIFU) for definitive treatment of prostate cancer". BJU International 2012; 110; 1228-1242

3 Crouzet S, Murat FJ, Pasticier G, Cassier P, Chapelon JY, Gelet A. "High intensity focused ultrasound (HIFU) for prostate cancer: current clinical status, outcomes and future perspectives." Int J Hyperthermia 2010 ; 26 : 796 - 803

4 Crouzet S, Poissonnier L, Murat FJ et al. "Outcomes of HIFU for localised prostate cancer using the Ablatherm Integrate Imaging(R) device" . Prog Urol 2011 ; 21 : 191 - 7

5 Illing R, Chapman A. "The clinical applications of high intensity focused ultrasound in the prostate". Int J Hyperthermia 2007; 23; 183-191

6 Karakan T, Diri A, Hascicek AM et al. "Comparison of Ultrasonic and Pneumatic Intracorporeal Lithotripsy Techniques during Percutanenous Nephrolithotomy". Scientific World Journal 2013; 2013

7 Liatsikos EN, Dinlenc CZ, Fogarty JD et al. "Efficiency and efficacy of different intracorporeal ultrasonic lithotripsy units on a synthetic stone model". J Endourology 2001; 15; 925-928

8 ☆ Phillips JM, Narula N, et al. "Histological evaluation of cold versus hot cutting: clinical impact on margin status of laparoscopic partial nephrectomy". J Urol: 2008: 180 : 2348-2352

9 Strate T, Bloechle C et al. "Hemostasis with the ultrasonically activated scalpel." Surg Endosc: 1999: 13 (727)

10 Toyaki U, Shiro B, Akira I et al "Transrectal high intensity focused ultrasound in the treatment of localized prostate cancer: A multicenter study." Acta Urol; 2005 ; 51

11 Wein "Surgical Management of Upper Urinary Tract Calculi" Campbell's Urology, Ch 48

12 Wein "Fundamentals of Laparoscopic and Robotic Urologic Surgery" Campbell's Urology, Ch 9

13 Wein "High Intensity Focused Ultrasound for the Treatment of Prostate Cancer" Campbell's Urology, Ch 106