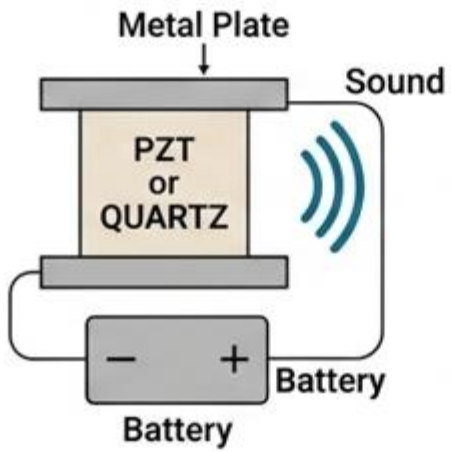
High-Intensity Focused Ultrasound as a Non-Invasive Thermal Ablation Technique

Amer D. Majeed

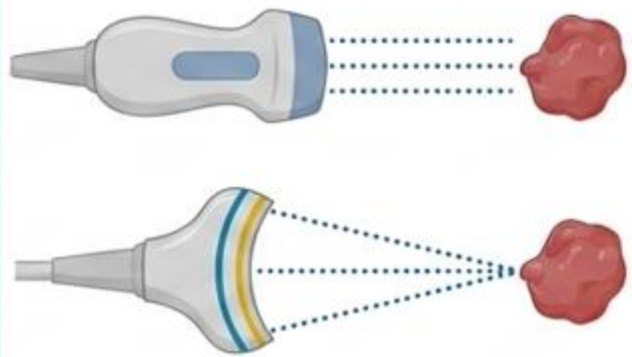
The Physics of Energy Transformation

Step 1: Electrical to Mechanical



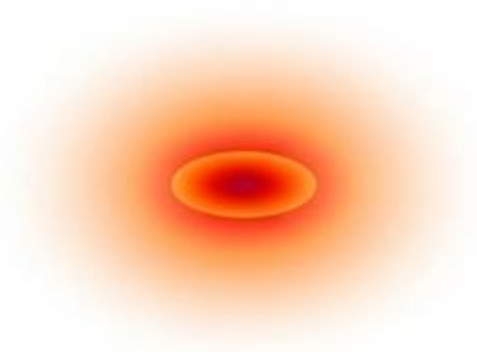
Piezoelectric transducers (PZT or Quartz) convert electrical voltage into mechanical vibrations, generating high-frequency sound waves.

Step 2: Mechanical to Acoustic



These waves propagate through the tissue. Phased arrays or curved lenses dictate the trajectory, transitioning from parallel diagnostic beams to heavily converging therapeutic beams.

Step 3: Acoustic to Thermal

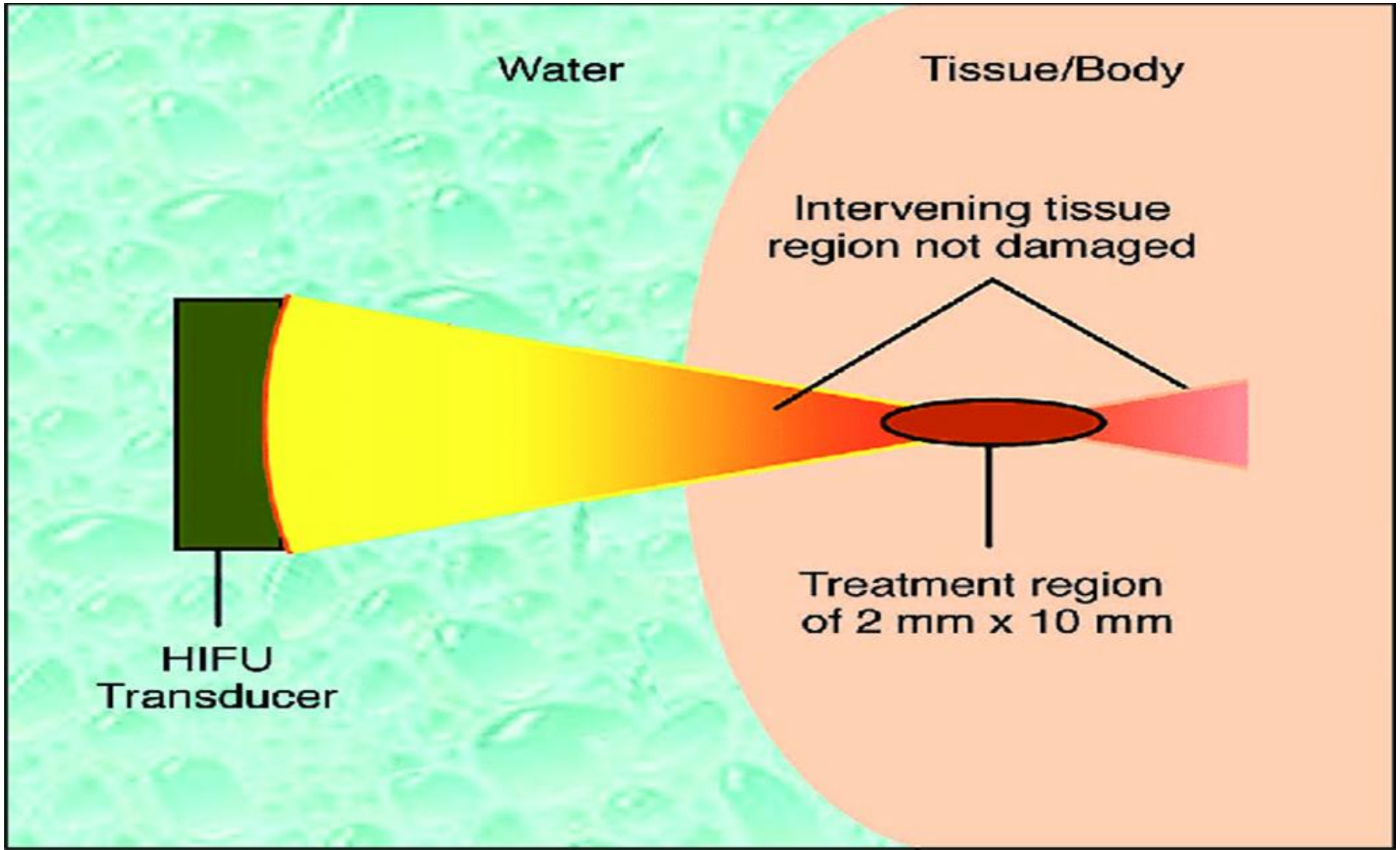


The convergence massively increases acoustic intensity at the focal spot. The tissue absorbs this concentrated kinetic energy, converting it rapidly into localized heat.

Focusing of Ultrasound Waves

Focusing of acoustic energy → increases intensity at focal spot

. This focusing increases the intensity of the ultrasound at the focal point, allowing for precise targeting of tissue.



Conversion of acoustic energy into heat (absorption).
High-Intensity Focused Ultrasound – focused ultrasound energy to concentrate heat in small volumes at specified depth
Non-invasive modality
Uses: originally tumor ablation; now used for skin tightening, lifting, pigmentation, etc.

Dual Mechanisms of Cellular Destruction

Thermal Effects

Trigger:
High absorption of concentrated acoustic energy.

Reaction:
Rapid focal heating to 60-100°C.

Biological Outcome:
Immediate protein denaturation and coagulative necrosis. Cell death occurs faster than tissue vasculature can dissipate the heat.

Mechanical Effects

Trigger:
Extreme acoustic radiation force and pressure changes.

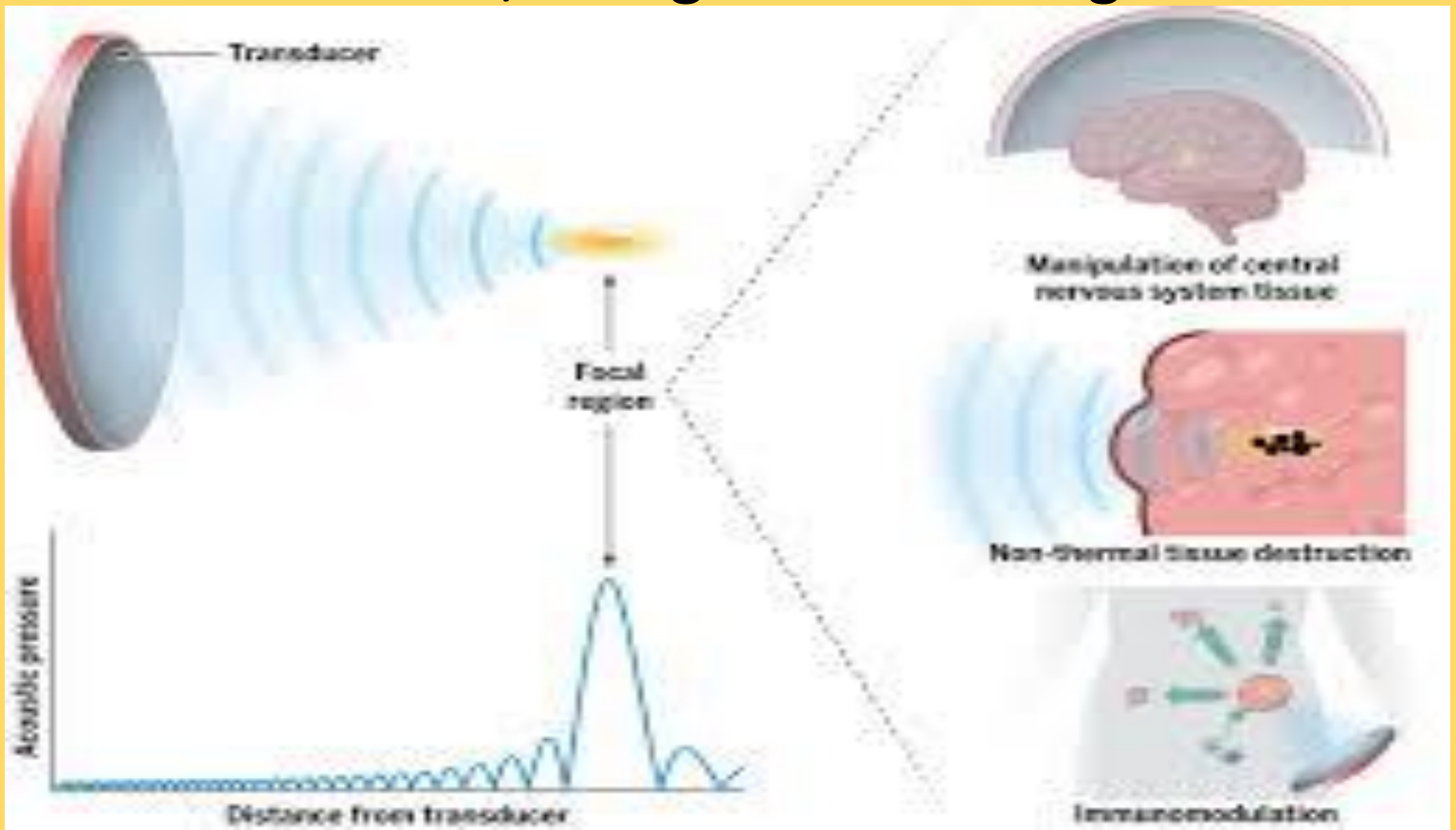
Reaction:
Micro-streaming jets and high shear stress against cell walls.

Biological Outcome:
Cellular pitting and targeted apoptosis. Endonucleases degrade the DNA of the disrupted cells.

Thermal & Mechanical Effects

Tissue Heating: When the focused ultrasound waves penetrate tissue, they cause mechanical vibrations of the tissue molecules, generating heat. The temperature at the focal point can exceed 60-100°C, leading to coagulative necrosis of the targeted tissue.

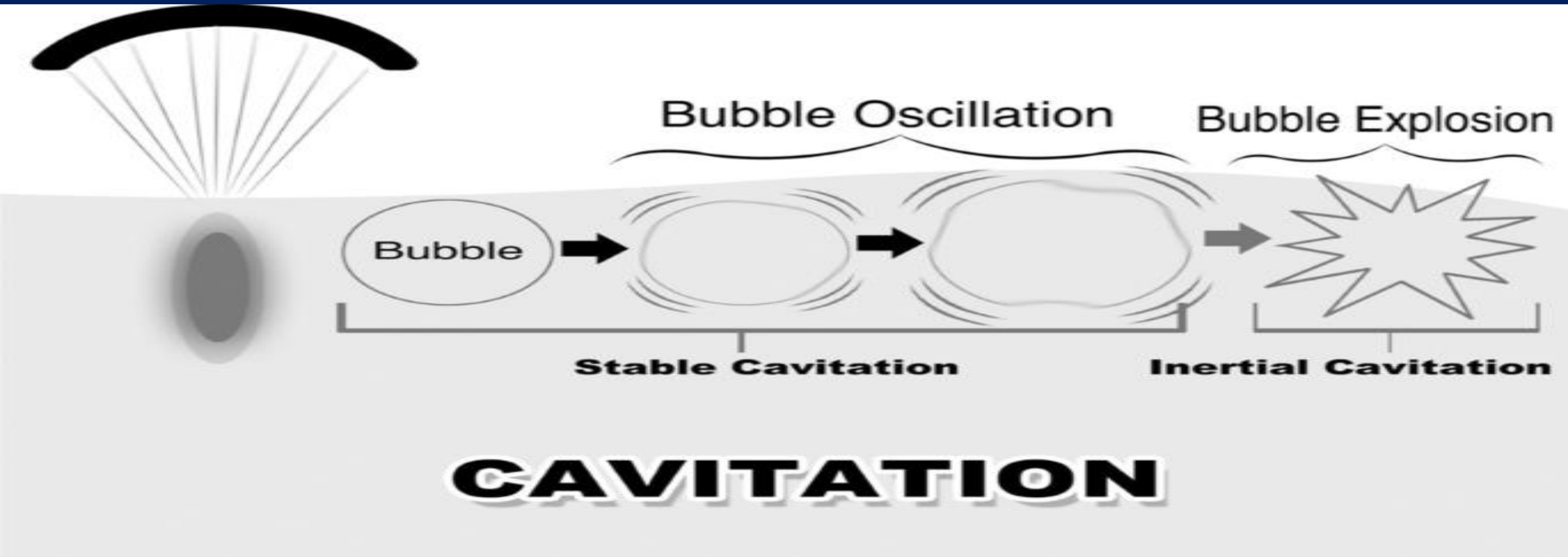
Thermal effect: at focal point, temp can rise (60-70°C) → protein denaturation, cell death, collagen remodeling



Cavitation

Mechanical effects: acoustic radiation force; possibly cavitation (formation of microbubbles) → mechanical disruption of cells

Bubble Formation: The rapid heating can cause the formation of microscopic bubbles in the tissue. These bubbles can expand and collapse, creating shock waves that further disrupt the surrounding tissue



Safety and Monitoring

Real-Time Imaging: HIFU systems often use ultrasound imaging to monitor the treatment process, ensuring that the energy is delivered accurately and that surrounding healthy tissue is preserved.

Real-Time Monitoring and Delivery Guidance

HIFU requires precise, real-time imaging to ensure energy targets the pathology and spares healthy tissue.

USgFUS (Ultrasound-Guided)

- **Modality:** Sonography.
- **Advantages:** Highly cost-effective, exceptional real-time temporal resolution, seamlessly integrated with the therapeutic transducer.

MRgFUS (MRI-Guided)

- **Modality:** Magnetic Resonance Imaging.
- **Advantages:** Superior 3D anatomical detail, capable of real-time thermometry (precise temperature mapping of the focal spot).

The ability to focus an ultrasound beam and its energy onto millimeter-size targets was a significant milestone in the development of therapeutic applications of focused ultrasound. Focused ultrasound can be used as a non-invasive thermal ablation technique for tumor treatment and is being developed as an option to standard oncologic therapies.

High-intensity focused ultrasound has now been used for clinical treatment of a variety of solid malignant tumors, including those in the pancreas, liver, kidney, bone, prostate, and breast, as well as uterine fibroids and soft-tissue sarcomas.

Three Vectors of Acoustic Delivery

Vector 1: Extracorporeal (External)

Method: Delivered through the skin via an acoustic window.

Primary Targets: Accessible organs like the Kidney, Liver, and Breast.

Vector 3: Interstitial (Endoscopic)

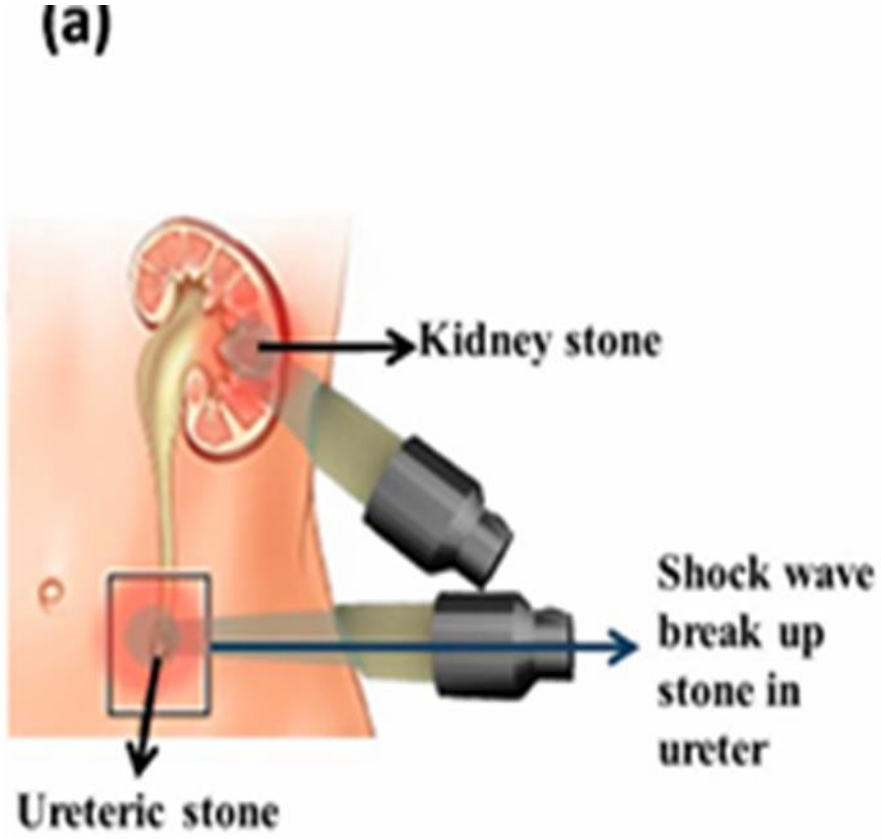
Method: Miniaturized probes inserted via the mouth or bodily ducts.

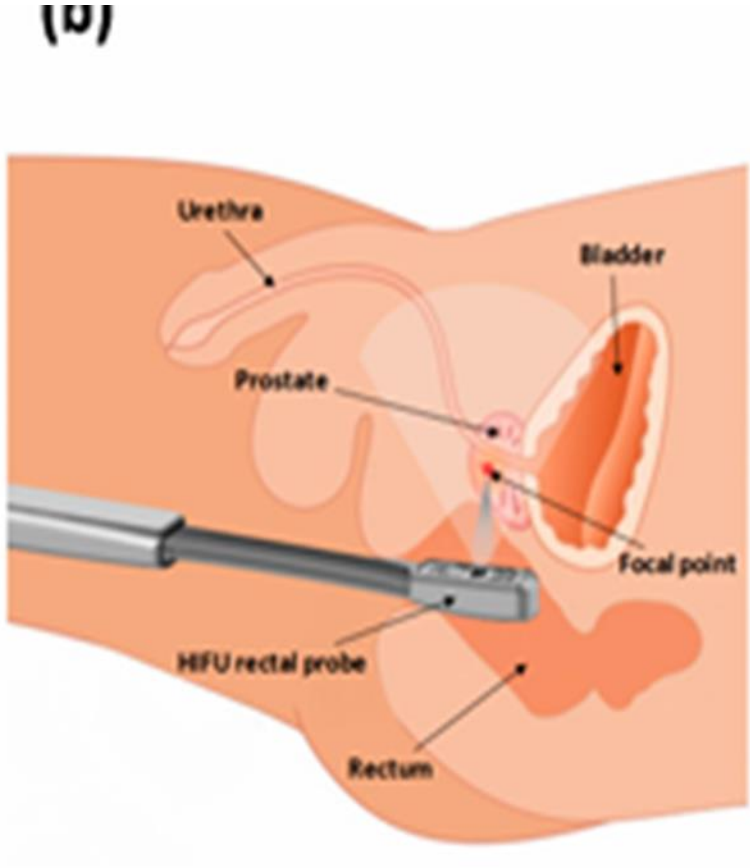
Primary Targets: Difficult-to-reach luminal tumors in the Esophagus or Biliary ducts.

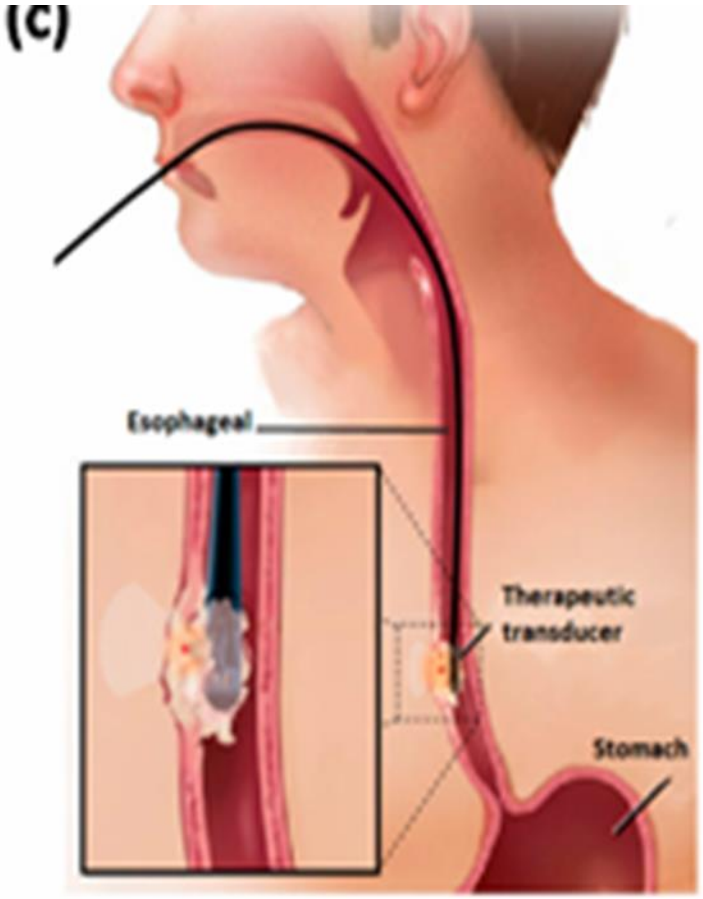
Vector 2: Transrectal (Cavity Insertion)

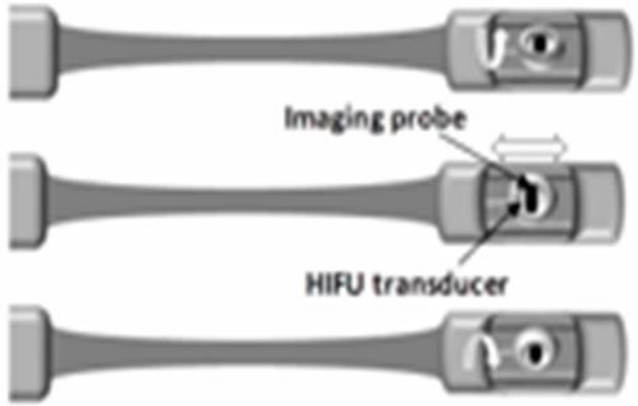
Method: Endocavitary probes placed in close proximity to the target.

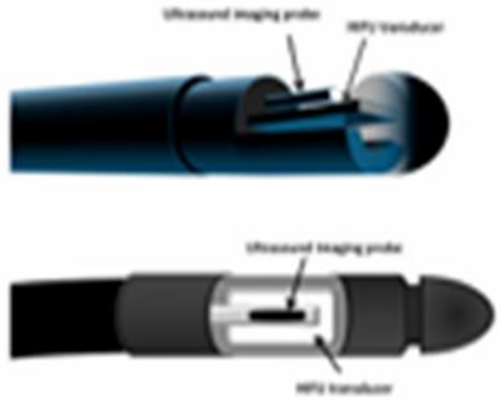
Primary Targets: Prostate cancer and prostate hypertrophy.

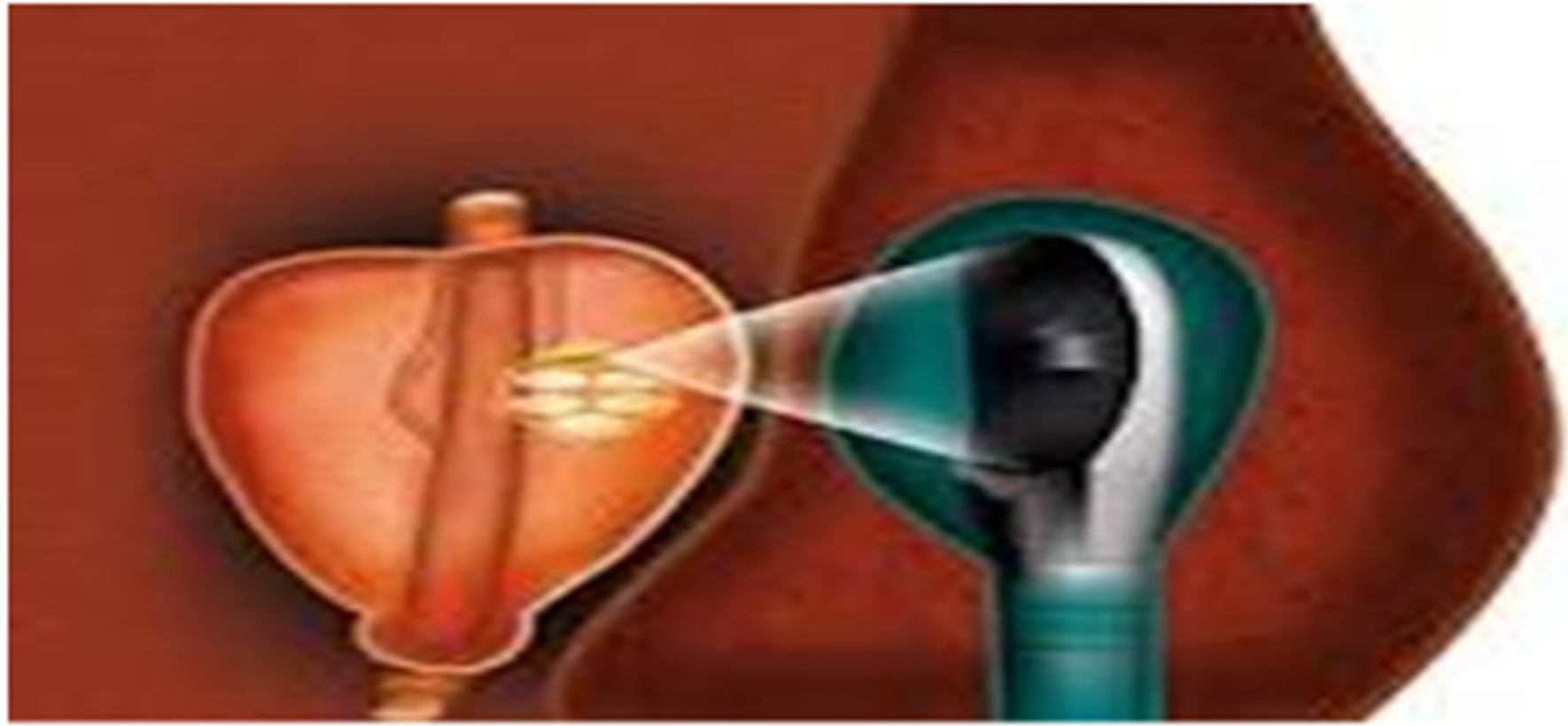

(a)
Kidney stone
Shock wave
break up
stone in
ureter
Ureteric stone


(b)
Urethra
Bladder
Prostate
Focal point
HIFU rectal probe
Rectum


(c)
Esophageal
Therapeutic
transducer
Stomach


Imaging probe
HIFU transducer





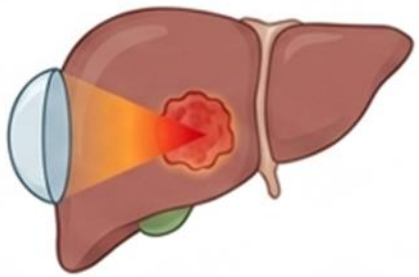
Focal High Intensity Focused Ultrasound Effective for Treating Prostate Cancer

Clinical Oncology: Extracorporeal Tumor Ablation

Core Benefits:

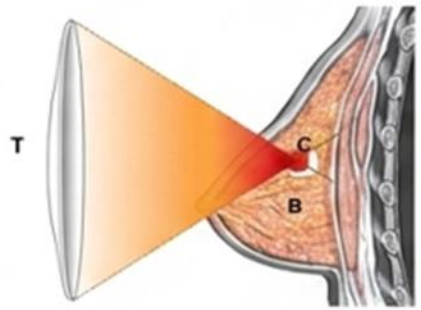
Completely non-invasive, non-ionizing, absence of surgical scars, shorter recovery, and highly viable for primary solid and metastatic tumors.

Liver



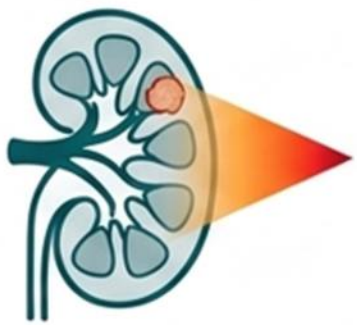
Effective for Hepatocellular carcinoma (HCC).
Selectively ablates distributed, multi-centric tumor nodules that make surgical resection highly risky.

Breast



Ideal for breast-conservation therapy (invasive lobular, ductal).
Negates anesthesia risks and preserves skin integrity.

Kidney



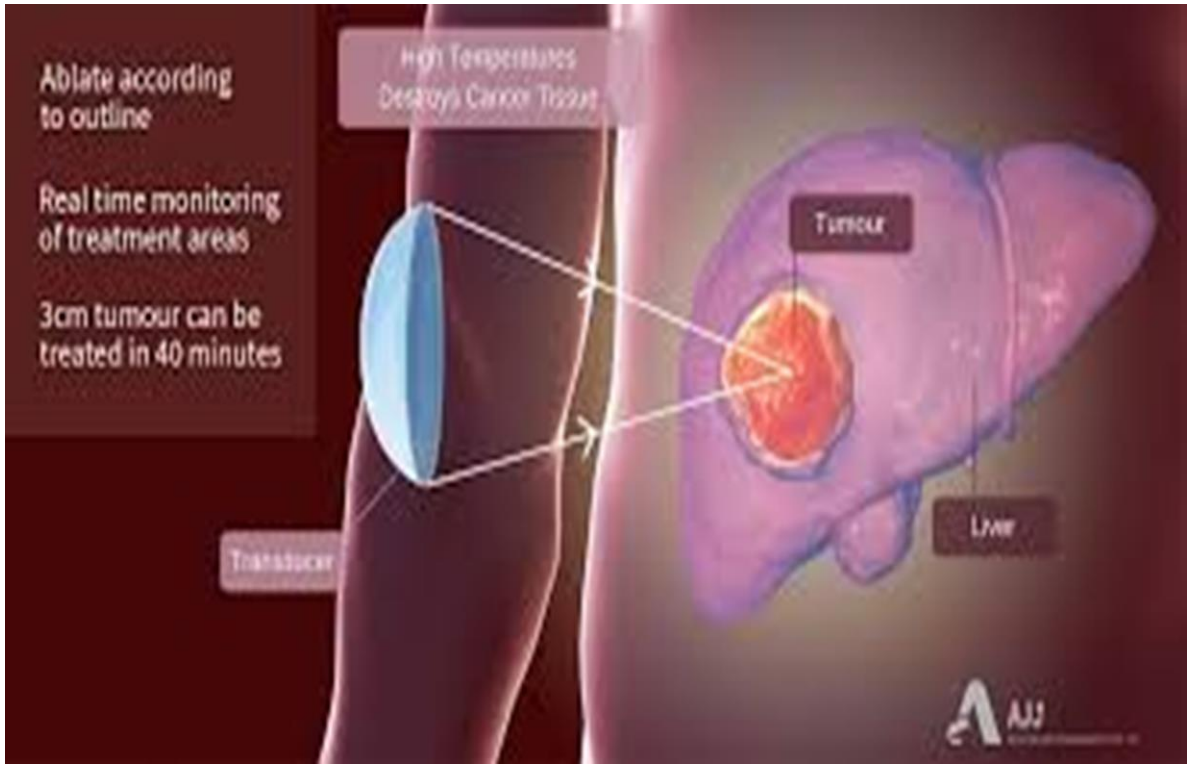
Highly attractive alternative to total/partial nephrectomy for small renal tumors.
Yields irreversible, homogenous cell damage.

Pancreas

Ultrasound-guided extracorporeal delivery destroys tumor mass while sparing sensitive surrounding vascular structures.

Liver

Hepatocellular carcinoma (HHC), is one of the most common and often one of the most di cult to treat liver cancer, especially when multi centric. This can make the outcome of surgical resection poor, with high risk of tumor recurrence. Extracorporeal HIFU has enabled selective ablation of distributed liver tumor nodules.

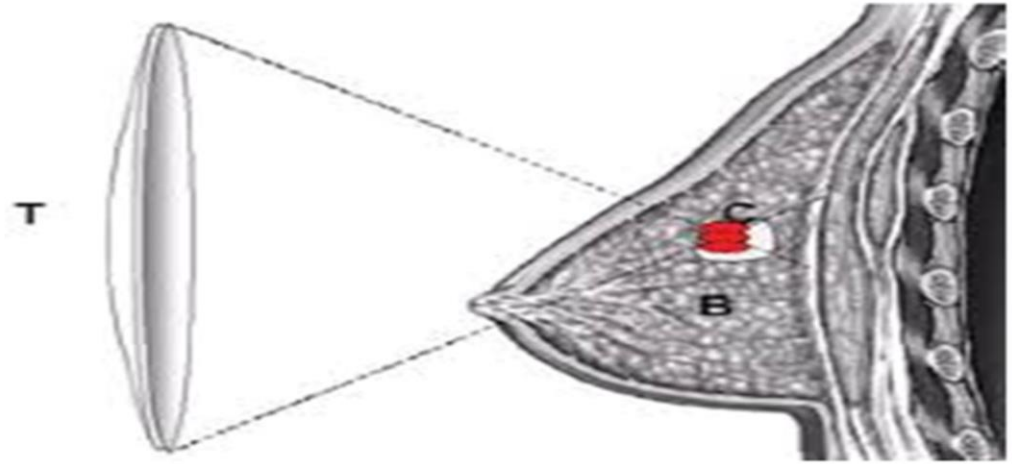


Breast

HIFU can be an effective nonsurgical technique for breast cancer treatment particularly for high-surgical-risk patients and breast-conservation therapy. This is because of its local tumor necrosis effect, lessened requirement for anesthesia, shorter recovery time, lower infection risk, and absence of scar formation or compromised skin integrity. HIFU has been applied for treating different breast cancers including invasive lobular carcinoma, ductal carcinoma, and mucinous.

Nevertheless, HIFU treatment can effectively

induce tumor destruction and loss of propagation activity in breast tumors



High-intensity focused ultrasound in the treatment of breast tumors

Kidney

When renal tumors are small in size, non-invasive HIFU ablation therapy is an attractive alternative method compared to total or partial nephrectomy.

The few clinical studies that have examined HIFU for ablation of kidney cancer tumors have reported promising outcomes of histology-proven irreversible and homogenous damage of treated areas

Esophagus

cancer is often identified as a small localized intraluminal squamous-cell carcinoma. Common treatment methods involve surgery and chemotherapy with or without radiation therapy. These methods have overall poor outcomes; with 5-year survival rates of 13–18%].

The HIFU system used was an axial-rotating, interstitial ultrasound ablator probe enabling sectorial or cylindrical tumor volumes treatment, with a specialized transducer for delivering parallelepiped-shaped, high-intensity beam

Pancreatic

Extracorporeal HIFU devices used for pancreatic treatment include ultrasound-guided

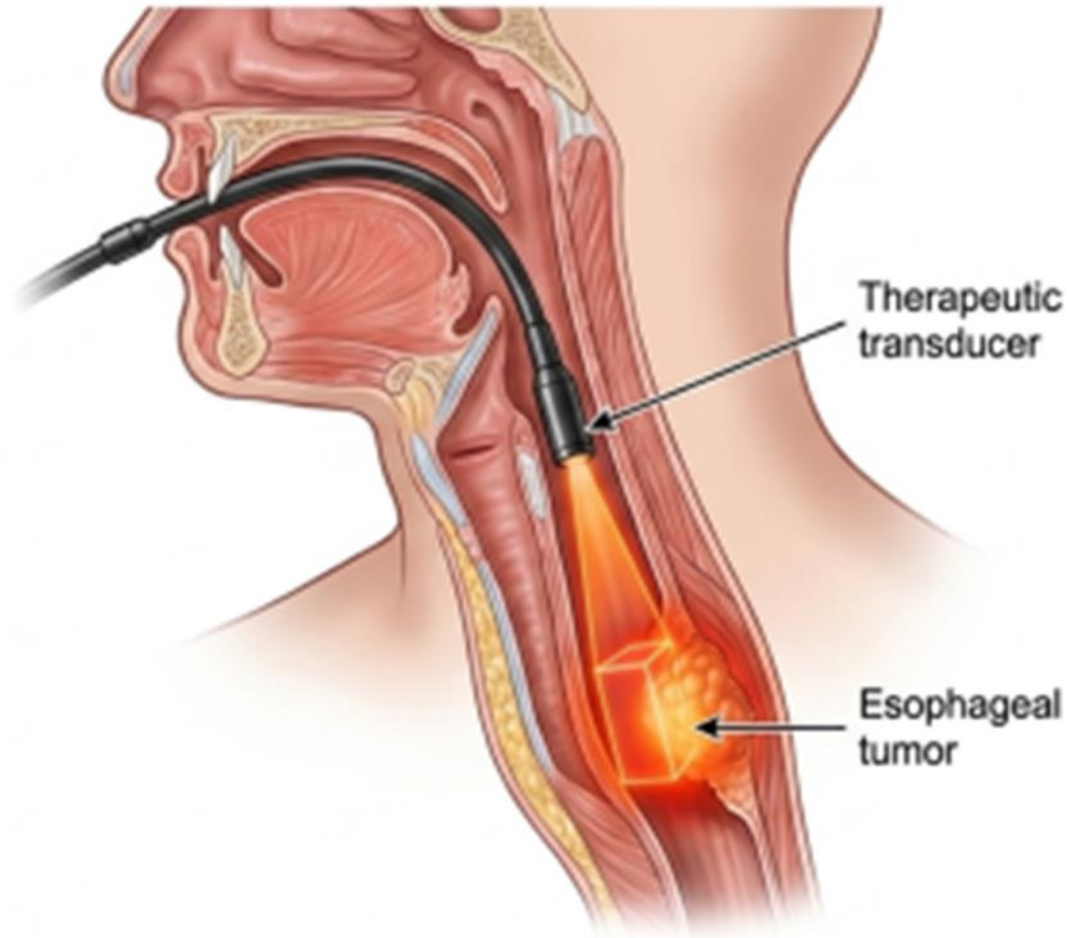
Complex Oncology: Interstitial Targeting

Context

Esophageal cancer often presents as localized intraluminal squamous-cell carcinoma. Traditional surgery, chemo, and radiation yield poor 5-year survival rates (13–18%).

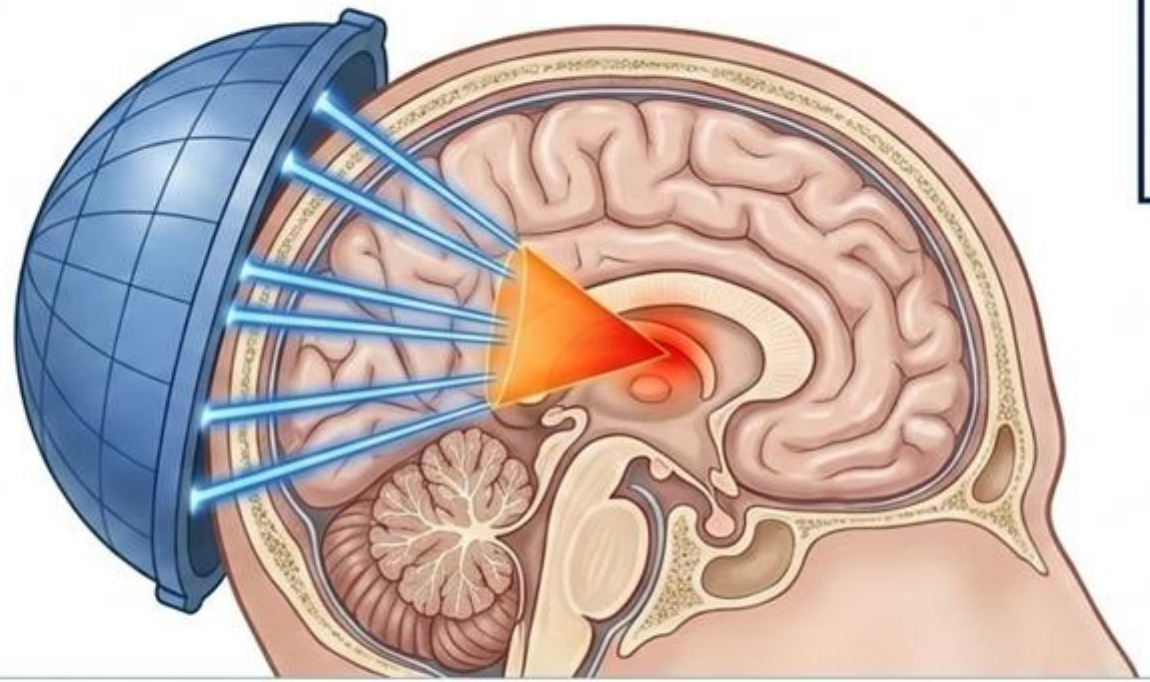
The HIFU Solution

- Utilizes a specialized axial-rotating, interstitial ultrasound ablator probe.
- Inserted non-surgically through the mouth.
- The transducer delivers a unique parallelepiped-shaped (3D rectangular) high-intensity beam.
- Through rotation, it creates precise sectorial or cylindrical ablation volumes perfectly matched to the tubular structure of the esophagus.



Neurology: Breaching the Intact Skull

The Breakthrough: HIFU successfully transmits and focuses acoustic energy through the rigid, intact human skull to millimeter-sized targets, enabling **non-invasive intracranial ablation**.



Application 1: Glioblastoma & Tumors

Bypasses the Blood-Brain Barrier (BBB), which traditionally prevents systemic chemotherapy from reaching diffuse central nervous system tumors.

Application 2: Brain Disorders

Facilitates precise local ablation to treat neurological and movement disorders, including Essential Tremor (ET), Parkinson's Disease (PD), Alzheimer's, and epilepsy, entirely replacing open neurosurgical procedures.

Brain

Glioblastoma is the most common malignant tumor of the central nervous system. It is commonly treated with surgical resection and chemo/radiation therapy.

Main challenges in management of brain tumor is the di use spread of the tumor throughout the brain and inability of chemotherapy regimen to cross blood brain barrier (BBB).

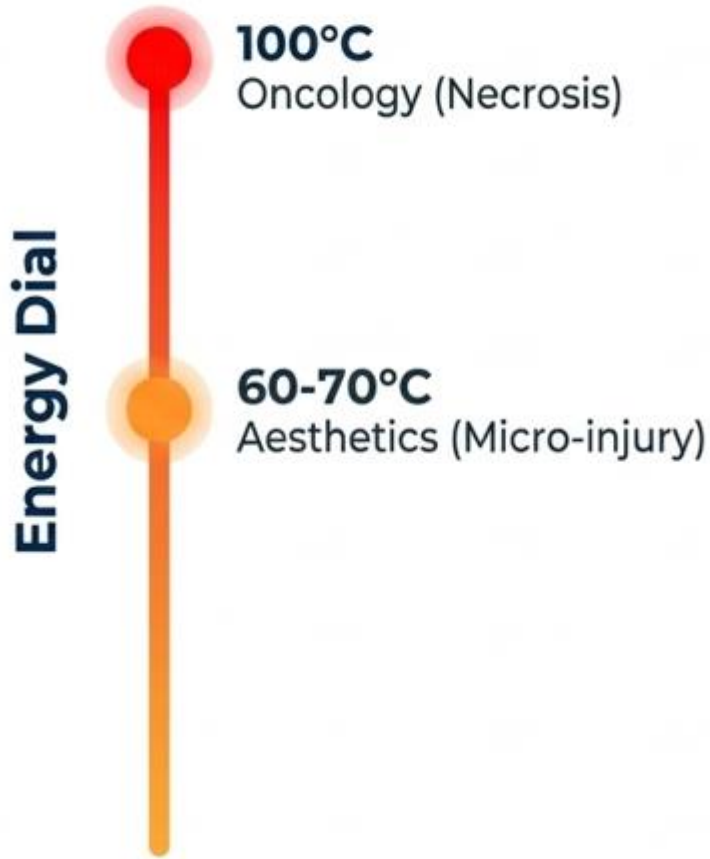
HIFU, due to its ability to transmit and focus acoustic energy through intact skull and target small areas, has been studied to address these challenges over the past decade with clinical progress mainly in tumor ablation.

Brain Disorders

The ability to focus and target the US beam through the intact skull to areas as small as a couple of millimeters has been a considerable milestone in enabling precise, local ablation of intracranial brain tissue to overcome certain brain disorders. HIFU has been investigated for treating different brain disorders including movement disorders (essential tremor; ET), Parkinson's disease (PD) and Alzheimer's disease (AD), depression/anxiety and pain syndromes-186, epilepsy, thrombolysis/intracerebral hemorrhage , and cerebrospinal fluid (CSF) diversion

The Shift to Aesthetics: From Ablation to Stimulation

In cosmetic medicine, HIFU uses lower energy to heat the deeper dermal layers layers to 60°C–70°C without harming the surface epidermis.



The Biological Cascade

Step 1: Controlled Damage

The targeted thermal coagulation creates controlled micro-injuries in the tissue.

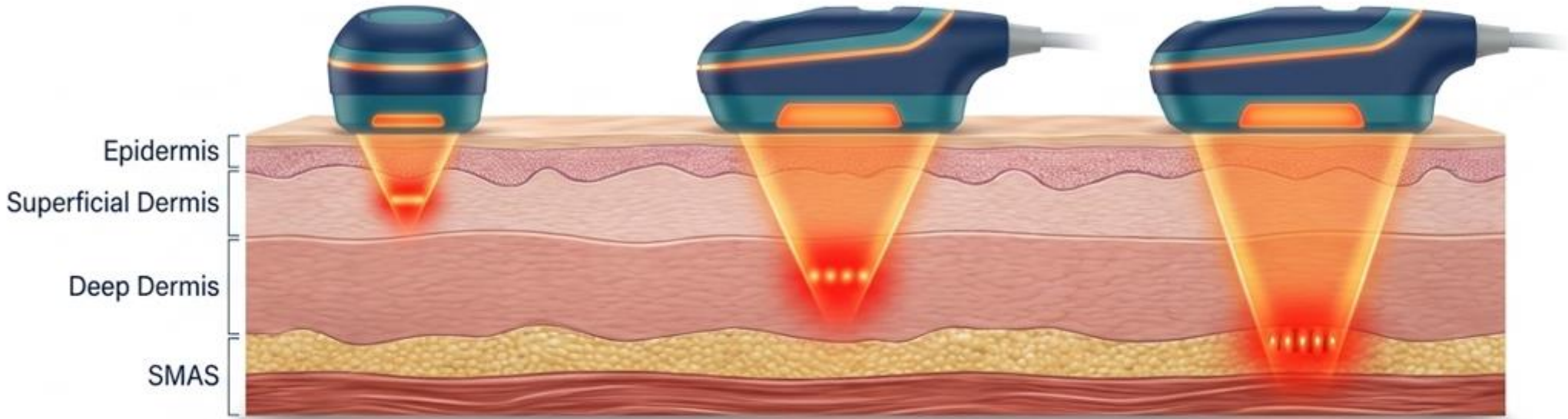
Step 2: Healing Response

The body perceives this thermal damage and triggers a natural healing response. Fibroblasts are activated, forcing the robust synthesis of new collagen and elastin fibers.

Step 3: Structural Remodeling

Result: Gradual structural remodeling resulting in tighter, lifted skin over several months.

The Architecture of Aesthetic Targeting



1.5mm (Superficial Dermis)	3.0mm (Deep Dermis)	4.5mm (SMAS Layer)
Target: Melanocytes and melanin-rich cells.	**Target:** Structural collagen layer.	**Target:** The foundational connective tissue.
Mechanism: Sonophoresis and mechanical destruction of pigment granules. Stimulates epidermal turnover.	**Mechanism:** Thermal micro-injuries trigger fibroblast activation and collagen remodeling.	**Mechanism:** Thermal coagulation of the exact layer plastic surgeons manipulate during traditional face-lifts.
Outcome: Reduces hyperpigmentation, yielding brighter, even skin tone.	**Outcome:** Significant tightening effect, reducing fine lines and wrinkles.	**Outcome:** Deep structural lifting of the face and neck.

Ultrasound waves are increasingly used in various cosmetic and medical treatments due to their ability to penetrate tissues and stimulate cellular processes.
Here's an overview of their applications in treating skin pigmentation, sagging skin, and waist fat removal:

At 1.5mm – Superficial Dermis Layer:

Focusing HIFU energy at this depth targets melanin in the skin and reduces pigmentation, resulting in brighter and more even skin tone.

At 3.0mm – Deep Dermis Layer:

Focusing HIFU energy at this depth targets skin tightening. The energy stimulates structural collagen production hence resulting in a tightening effect, improving fine lines and wrinkles.

At 4.5mm – Superficial Muscular Aponeurotic System (SMAS):

The SMAS layer is where plastic surgeons target during a traditional surgical facelift procedure, which means that stimulation and tightening of the SMAS layer results in a lifting effect of the treatment area.

Clinical Evidence: Non-Surgical Rejuvenation

Pigmentation Resolution (1.5mm Depth)

High-frequency acoustic waves break down localized melanin deposits. Collagen remodeling simultaneously smooths the texture, reducing the appearance of pigment irregularity without chemical peeling.

SMAS Lifting (4.5mm Depth)

Targeted thermal coagulation in the superficial muscular aponeurotic system induces a physical contraction of the tissue.
Yields a non-invasive lift for sagging skin across the face, neck, and décolletage over a 3-to-6 month remodeling window.

Treatment of Skin Pigmentation

Mechanism: Ultrasound waves can enhance the penetration of topical treatments, such as lightening agents, into the skin. This is achieved through a process called sonophoresis, which uses sound waves to increase the permeability of the skin.

Benefits: The targeted ultrasound can help break down melanin deposits, reducing hyperpigmentation and achieving a more even skin tone. Additionally, ultrasound stimulates collagen production, which can improve overall skin texture.

How Does HIFU Treat Pigmentation?

Heat damages melanocytes / melanin-rich cells → reduces pigment production or deposits. Stimulates epidermal turnover (skin peeling or renewal)

Collagen remodeling improves texture which may reduce appearance of pigment irregularity May have mechanical destruction of pigment granules.

Treatment of Sagging Skin

Mechanism: Ultrasound treatments, particularly focused ultrasound, are used to heat the deeper layers of the skin without damaging the surface. This heating triggers a natural healing response, stimulating collagen production and tightening the skin.

Benefits: This non-invasive approach can lift and firm sagging skin, especially in areas like the face, neck, and décolletage. The results are gradual and can improve over several months as collagen continues to regenerate. HIFU stimulates collagen production through targeted thermal energy that creates micro-injuries in the dermis, triggering the body's natural healing processes. This leads to increased collagen synthesis, resulting in tighter, more youthful-looking skin over time.

The focused energy generates heat (usually between 60°C to 70°C) within the dermis, the layer of skin where collagen fibers are located. This heat causes controlled thermal coagulation, which leads to micro-injuries in the tissue without damaging the overlying skin.

Tissue Response:

The body perceives these micro-injuries as damage, prompting a natural healing response.

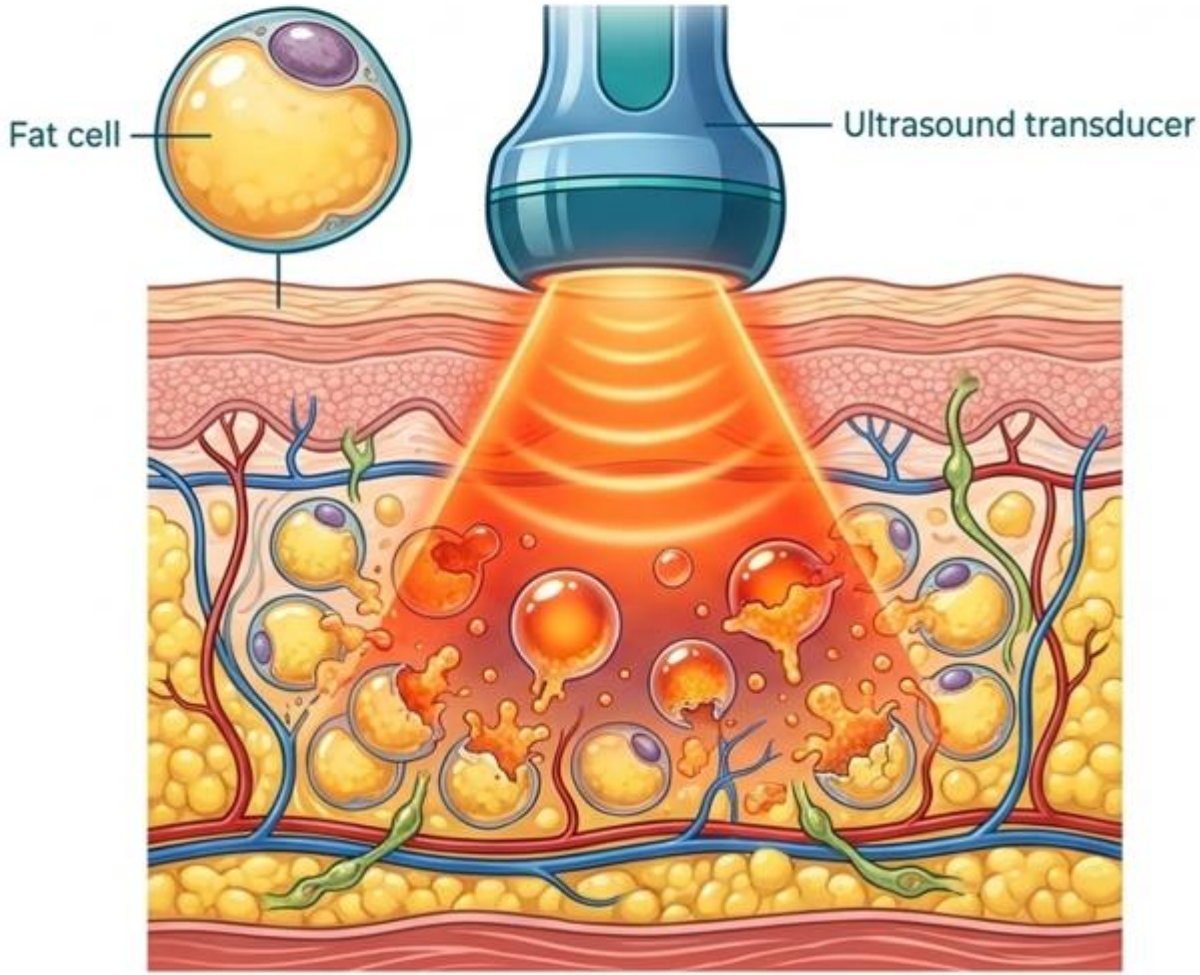
This response involves the activation of fibroblasts, the cells responsible for collagen synthesis.

As fibroblasts are activated, they begin to produce new collagen and elastin fibers.
Over time (typically several months), the new collagen formation leads to improved skin texture, firmness, and elasticity.
Long-Term Effects:

The effects of HIFU are not immediate; they develop gradually as collagen remodeling occurs.
The results can last for several months to a year, depending on individual factors such as skin type, age, and overall health.

Adipose Targeting: Ultrasound Cavitation

The Mechanism: Unlike the high-frequency thermal approach used for skin tightening, waist fat reduction utilizes low-frequency ultrasound waves.



The Process

Acoustic waves penetrate the hypodermis, targeting localized fat deposits.

↓

They induce the cavitation phenomenon (stable to inertial bubble collapse) exclusively within the fat cells.

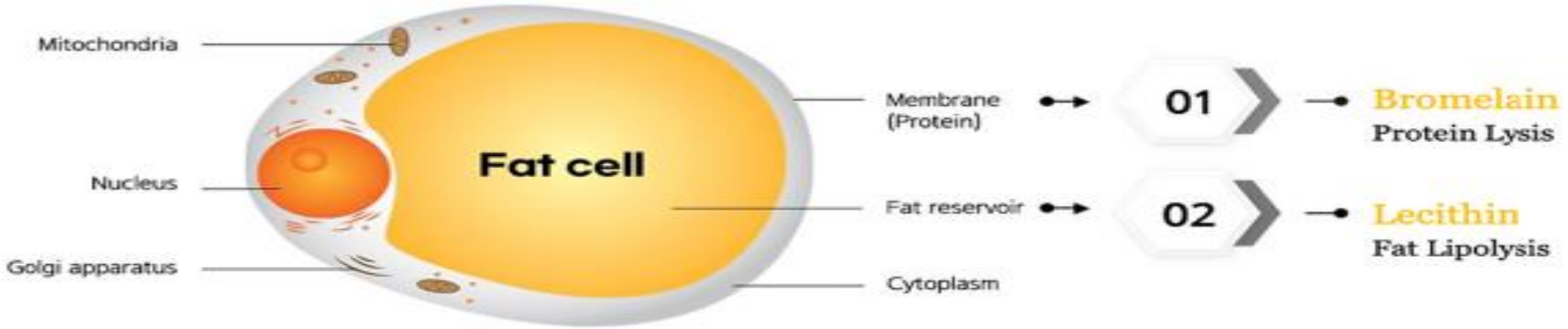
↓

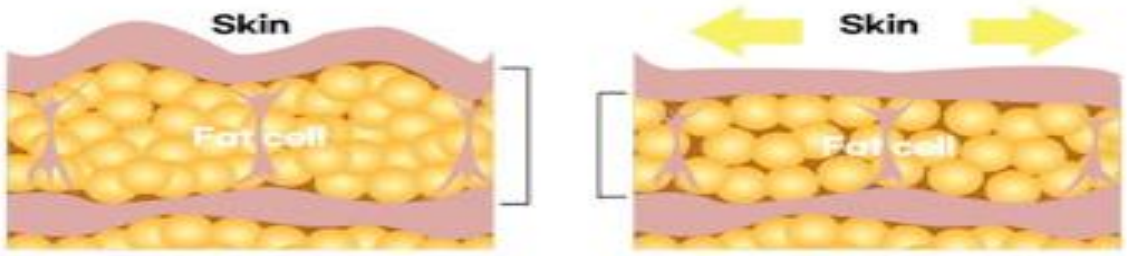
The imploding bubbles physically rupture the fat cell membrane. The destroyed fat contents are released safely into the bloodstream, where they are naturally metabolized and eliminated by the body, resulting in non-surgical waist reduction.

Removal of Waist Fat

Mechanism: Ultrasound cavitation is a technique that uses low-frequency ultrasound waves to target and break down fat cells in specific areas, such as the waist. The ultrasound waves create bubbles in the fat that implode, leading to the release of fat into the bloodstream for elimination by the body.

Benefits: This non-surgical method can reduce localized fat deposits without the need for anesthesia or downtime. Patients may see noticeable reductions in waist circumference after a series of sessions.

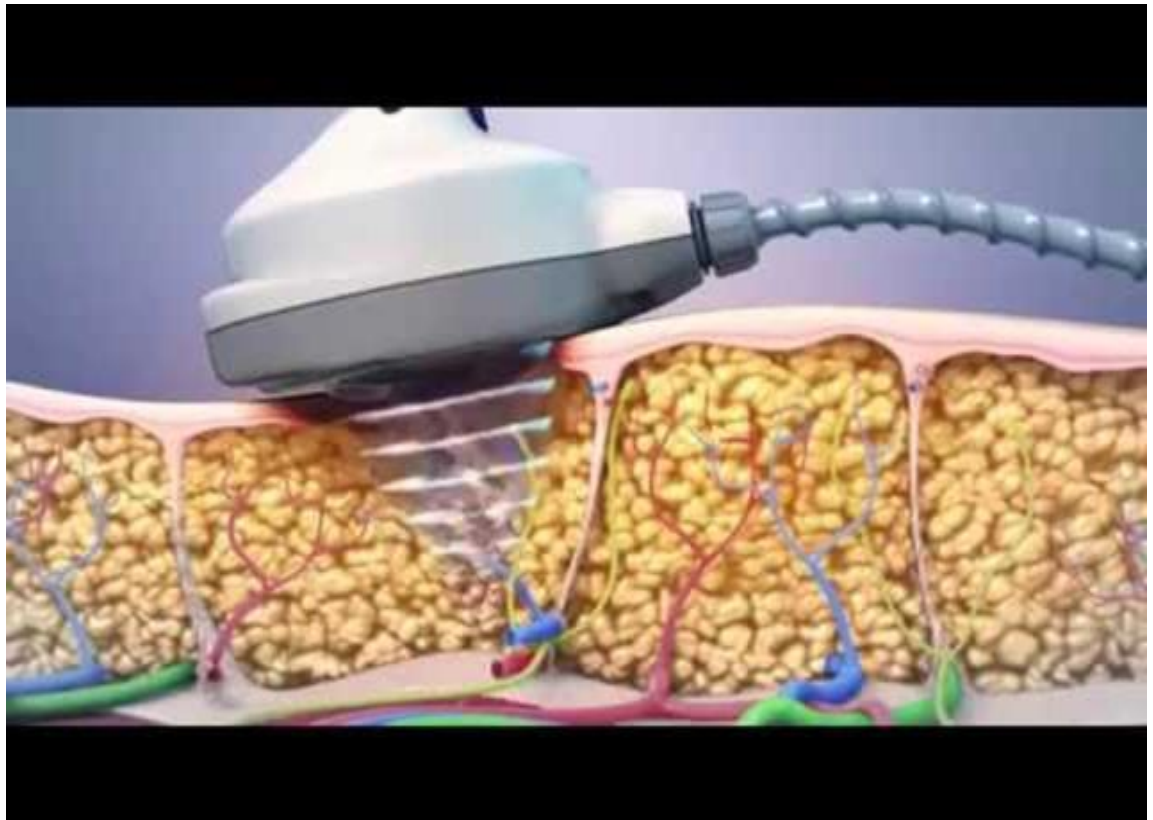




03

Riboflavin
fat metabolism booster
Skin regeneration
Antioxidant

Ultrasound waves offer innovative solutions for cosmetic treatments, providing non-invasive methods to address skin pigmentation, sagging skin, and localized fat. These procedures are generally safe and effective, but it's essential for individuals to consult with qualified professionals to determine the most appropriate treatment for their specific needs.



The Unified Acoustic Spectrum

HIFU represents a profound paradigm shift in modern medicine. By manipulating just three variables—frequency, focal geometry, and intensity—a single non-ionizing technology transforms into a universal acoustic scalpel.

High Energy / Deep Focus

Low Energy / Shallow Focus

High Intensity

Oncology & Neurology (60-100°C).
Deep tissue penetration, coagulative necrosis, tumor ablation, BBB breaching.

Medium Intensity

Adipose Reduction
Low-frequency mechanical cavitation, targeted cell membrane rupture.

Low Intensity

Aesthetic Medicine (60-70°C)
Shallow focal depth, thermal micro-injuries, neocollagenesis, SMAS lifting.

A truly non-invasive future spanning the entire spectrum of human health and aesthetics

THANK YOU