

Ultrasonic Energy in Endoscopic Surgery

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Abstract

The Harmonic Scalpel made by Ultracision is a system for endoscopic cutting. The energy source is vibration. The power box is attached to a forceps or blade, and the vibrational frequency of the blade approaches 55,500 cycles/second. This causes a knife-like action of the blade through tissue, with enough heating to create coagulation of small vessels. When this vibration energy is applied to the forceps configuration, coagulation occurs. By rotating the bottom blade of the forceps, the instrument becomes like a pair of scissors, and the tissue can divide. The Harmonic Scalpel allows the operator to cut using a tactile tissue. No smoke is created, only microaromized water droplets which are rapidly absorbed by the peritoneak surface. The instrument is extremely safe in that only tissue which is touched is cut; the energy source cannot travel through air, such as can happen with electrosurgery and laser surgery.

Key Words: UltraCision

ULTRASOUND ENERGY

Various energy forms exist in the surgeon's armamentarium to achieve adequate dissection and/or hemostasis. One of these forms is ultrasonic energy. The ultrasonically activated scalpel [i.e. Harmonic Scalpel*] relies on the mechanical propagation of sound, or pressure waves, from an energy source, and those waves are then conducted to an active blade element.

Sound waves are longitudinal mechanical pressure waves that can be propagated in solids, liquids, or gases. There is a large range of frequencies of longitudinal mechanical waves, with audible sound waves being confined to the frequency range of 20 to 20,000 cycles per second, which can stimulate human hearing. A longitudinal wave with a frequency below 20 cycles per second, such as an earthquake wave, is called infrasonic. One whose frequency is above the audible range is called an ultrasonic wave.

Ultrasonic waves may be produced by applying electromagnetic energy to either piezoelectric [also

termed electrostrictive] or magnetostrictive transducers, which create mechanical vibration in response to electric or magnetic fields, respectively. When ultrasonic waves are applied at lower levels, no tissue effect occurs, as is the case for diagnostic ultrasound imaging. However, higher sound wave power levels and power densities can be harnessed to produce surgical cutting, coagulation, and dissection of tissues.

THE HARMONIC SCALPEL

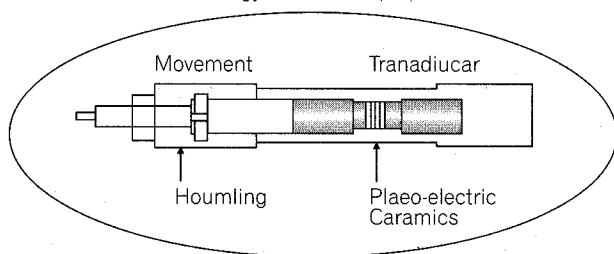
The Harmonic Scalpel is an ultrasonic surgical instrument for cutting and coagulating tissue, operating at a frequency of 55.5 kHz (or 55,500 cycles per second). The Harmonic Scalpel is composed of a generator, hand piece and blade. The hand piece (see Fig. 1) houses the ultrasonic transducer which consists of a stack of piezoelectric ceramics sandwiched under pressure between two metal cylinders. The transducer is attached to a mount which is then attached to the blade extender and blade. The generator is a microprocessor-controlled, high frequency switching power supply that drives the acoustic system in the handpiece with AC current. This results in vibration of the transducer at its natural harmonic frequency of 55.5 kHz. The microprocessor senses changes in the acoustic system to control power delivery and alert the user of system faults. The mechanical vibration established in the handpiece is conducted to a

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- Electrical energy from the generator is converted to mechanical energy at the hand piece



- Blade vibrates 55,500 (Hz) times per second

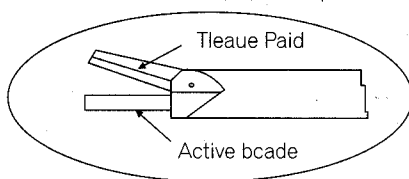


Fig. 1. Ultrasonic energy.

blade via an extender to make the system the appropriate length depending on the surgical application. The extender and blade shaft are housed in a protective sheath in a variety of diameters for laparoscopic and open surgery. The entire system vibrates harmonically at a frequency of 55.5 kHz with a maximum longitudinal displacement of 60–100 μm .

COAGULATION MECHANISM

The basic mechanism for coagulating bleeding vessels ultrasonically is similar to that of electrosurgery or lasers. Vessels are coapted by tamponading and sealed with a denatured protein coagulum. The manner in which protein is denatured, however, is different for each of these modalities. Electrosurgery and lasers. It reads like there is a word or words missing here from the coagulum by heating tissues to denature the protein. Desiccation (temperature above 100°C) is not necessary to coagulate vessels (Fig. 2). The temperature threshold for coagulation by the denaturation of protein forming the coagulum is 63°C. The tertiary structure of the protein uncoils as hydrogen bonds are disrupted. Usually the collagen denaturation is complete at 80 to 100°C. As protein cools, denatured protein forms a sticky coagulum weld, sealing off coapted vessels. The former uses electric current, whereas the latter uses light energy.

The Harmonic Scalpel denatures protein by the

Harmonic Scalpel

Electrosurgery/Laser surgery

50°C ← 100°C

150°C ← 400°C+

Protein disorganizes to form a coagulum

Vaporization of water desiccates tissues

Eschar forms when tissues burn

Fig. 2. Principles of ultracision technology in surgery.

Table 1. Thermal Damage According to Temperature Change

Energy modality	Temp C	Visual change	Biological change
Electrosurgery/Laser	37–50	Swelling	Heating, Retraction, Reduction of enzyme activity
	50–65	Blanching	Coagulation
	65–90	White/Gray	Protein denaturation
	90–100	Puckering	Drying of tissue
	>100	Drying of tissue	Bolling point of water. Cell explosion
	>150	charring	Carbonization
	300–400	Blackening	Smoke generation from carbonization

transfer of mechanical energy to the tissue, which is sufficient to break tertiary hydrogen bonds and by the generation of heat from internal cellular friction which results from the high frequency vibration of the tissue. Large vessels bleed when they're cut by the sharp edge of the scalpel, but not when the pressure is applied to them with the side of the blade, and blade is vibrated for a brief period of time [2–3 seconds]. Dr. Amaral states that in its current configuration, the Harmonic Scalpel dissecting tool blade can coagulate blood vessels in the 2 mm range without difficulty. The Harmonic Scalpel in blunt mode is able to coagulate vessels up to 5 mm in a diameter in laboratory tests and has been documented in use on 3 mm vessels in a clinical settings.

THERMAL EFFECT (Table 1)

Initial thermal studies indicated that heat generated as a result of stress and friction in the tissue is limited to temperatures below 80°C when a short energy time is used [personal communication, R.

Anderson, M.D. Wellman Laboratory, Massachusetts General Hospital]. As a result, tissue charring and desiccation from the loss of moisture can be minimized. The limited heat generation also minimizes the zone of thermal injury. This minimal thermal damage may explain the marked reduction in postoperative adhesions to the liver bed following laparoscopic cholecystectomy with the Harmonic Scalpel [22%] when compared to electrosurgery [66%] or laser surgery [77%] in experiments performed in pigs.

These mechanisms of coagulation offer an advantage for the Harmonic Scalpel over electrosurgery when coagulating the side wall of a blood vessel. In electrosurgery, the blood vessel is not coapted significantly because of the concomitant reduction in power density as the surface area of contact increases with coaptation. The blood within the vessels has a high heat capacity and acts as a sink. This allows one side to coagulate prior to the other with resultant bleeding from a hole in the wall of the vessel that was in contact with electrosurgery. In contrast, the Harmonic Scalpel relies on pressure and coaptation of the vessel walls for maximum energy transfer to the tissue. Thus, the vessel is sealed together without bleeding from the surface closest to the blade.

LAPAROSCOPIC COAGULATING SHEARS [LCS]

Pressure and coaptation are of paramount importance to the coagulative ability of the Harmonic Scalpel. In fact, unsupported tissue such as a transected bleeding vessel in a mesentery that cannot be compressed against a firm surface, is difficult to coagulate with a dissecting hook blade. To obviate this problem, the LCS was developed to include a vibrating blade with sharp and blunt edges, as well as passive [not ultrasonically activated] tissue pad with which tissue is pressed against the active, vibrating blade. This device allows unsupported tissue to be grasped and coagulated without difficulty, or cut and coagulated like a pair of scissors.

CUTTING MECHANISM

The two ultrasonic cutting mechanisms of the

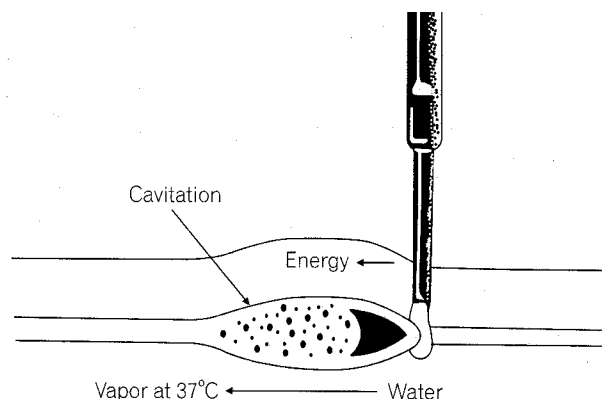


Fig. 3. Graphic depiction of cavitation effect.

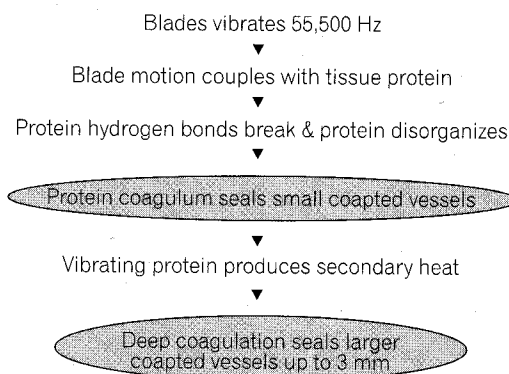


Fig. 4. Coagulation using ultracision technology.

Harmonic Scalpel are also different from that observed with electrosurgery or laser surgery. The first mechanism is cavitation cutting and fragmentation (Fig. 3). As the blade tip vibrates, it produces large transient pressure changes which cause intracellular and cellular water to vaporize at low temperature, rupturing cells, leading to very precise cutting and dissection. In addition, this cavitationally-created mechanism causes water vapor to expand between tissue planes, separating those tissue planes. This "cavitation effect" does not destroy tissue but enhances visualization of the vascular plane [dissection].

To achieve the cavitation effect [cavitation cutting and tissue plane separation] place the blunt blade surface on the distal tip of the dissecting hook, without applying great pressure on the tissue and activate the system.

The second mechanism for cutting by the Harmonic Scalpel, and the most important, is the actual "power cutting" offered by a relatively sharp blade

vibrating 55,500 times per second over a distance of 60–100 μm (Fig. 4). The blade edge cuts tissue by stretching it beyond its elastic limit [like breaking a rubber band by stretching it too far], and on a more microscopic level, by breaking molecular bands, as described above. The mechanical cutting effect is most easily achieved in high protein density areas such as collagen or muscle-rich tissues. In contrast, cutting with electrosurgery or lasers occurs when the temperature of the cells is increased above the boiling temperature of water, causing the water to vaporize, expand, and explode the cells.

Animal studies have demonstrated that the Harmonic Scalpel is similar in efficiency to an electro-surgical unit, with no difference in operative time, complications, or bleeding. The Harmonic Scalpel is superior with respect to avoidance of inadvertent gallbladder perforations, a finding replicated in humans. In addition, it eliminates many of the disadvantages of monopolar electrosurgery. The Harmonic Scalpel is able to cut and coagulate tissue with reduced generation of smoke compared to electrosurgery and lasers. Thus, there is minimal disruption of visualization during the procedure.

Although there is atomization of fluid which creates a transient mist, this does not accumulate, and it does not significantly impair the visual field as the droplets rapidly settle out. Furthermore, the Harmonic Scalpel eliminates the risks of electric injury. Finally, because there is little or no cutting ability with an unpowered blade, the blunt side of the Harmonic Scalpel can also be used as a blunt dissector (Fig. 5).

As a caution, it is suggested that the Harmonic Scalpel can, under some circumstances, create smoke, spray, and mist which may be harmful to surgical personnel. Studies of electrosurgical smoke recommend

using a surgical mask and adequate ventilation of the smoke using a surgical smoke evacuator or other means.

For optimal tissue dissection, the following suggestions should be helpful the surgeons.

— Cutting effect in direction of pressure applied to the blade.

- as long as pressure is applied to activated blade, it will continue to cut, or penetrate.
- there is much less lateral damage with the Harmonic Scalpel than with electrosurgery or lasers i.e. 4X less lateral thermal damage [ref, Amaral] and no compromise of visualization.

— Cavitational effect ahead of blade assists separation of tissue planes;

- facilitates dissection; verses welding planes together or cuts through them, as with other thermal modalities.
- Permits more precise dissection.

Blunt dissection with inactivated blade is possible with the back of the blade, advanced 10 mm blade sheath, or closed LCS.

Dissection with obvious advantage in lysis of adhesions, transection of pedicles.

* no risk of stray current travelling path of least resistance, to burn bowel, etc.

In consideration of wound healing, the Harmonic Scalpel is considered to be helpful by decreasing lateral thermal damage. It can minimize tissue desiccation and charring promotes faster, stronger healing than with electro and laser surgery. It is well known that necrotic tissue associated with electric surgical char and lateral tissue damage resulting from ischemia inhibits wound healing and compromises strength of healing, then promotes dehiscence [wound separation]. The Harmonic Scalpel has also been shown to cause less gall bladder perforation when compared with electrosurgery in lap chole procedure and also to produce less postop adhesion in the porcine model. When the Harmonic Scalpel is used to incise and dissect in fatty or muscular tissue, small vessels and lymphatics are sealed, thereby decreasing seroma, swelling, bruising, and wound drainage. Harmonic Scalpel dissection is used in place of blunt dissection and intermittent electric coagulation in many cases. The result is better hemostasis and sealing of lymphatics. Anecdotally, we have received reports of decreased bruising, seroma, swelling, and

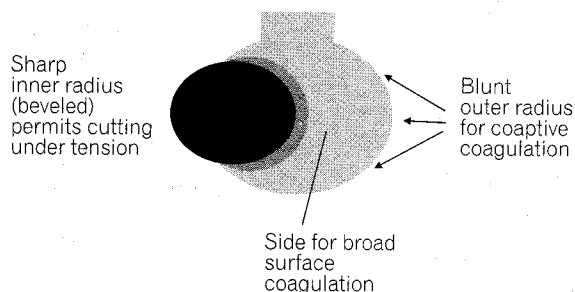


Fig. 5. Cutting and coagulation book.

wound drainage following open procedures for breast biopsy, mastectomy, and face lifts.

Regarding operative pain, the Harmonic Scalpel can avoid stimulation of nerves and muscles, while decreasing trauma to the tissue. Since there is no flow of current to the patient, HS does not pose the risk of electric nerve or muscle stimulation and therefore may cause less postop pain. Anecdotally, we have received reports of decreased postop pain following open-blade procedures such as hernia repair, breast biopsy, and radical prostatectomy, but this is not yet proven to be statistically significant when compared to electrosurgery.

CONCLUSION

The application of ultrasonic energy to endoscopic surgery offers many advantages over the use of electromagnetic energy, such as electrosurgery or laser surgery, without giving up the advantages of the latter energy forms. The Harmonic Scalpel allows tissue to be cut and coagulated with efficacy equal to that of electrosurgery. However, unlike electrosurgery, there are no risks of stray electrical current injury, grounding pad failures, or electrical injury to the operator, since there is no electrical current in the surgical field. In addition, because of lower heat generation, ultrasonic energy produces little smoke and minimal tissue charring and desiccation, leaving tissue planes and operative fields better visualized. You don't have to destroy tissue to stop bleeding.

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