**A Project Report**

**On**

**Cavitron Ultrasonic Surgical Aspirator (CUSA)**



Submitted by:

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**INTRODUCTION**

The Cavitron Ultrasonic Surgical Aspirator (CUSA) is a dissecting device that uses ultrasonic frequencies to fragment tissue.  This highly-specialized instrument is available at only a handful of veterinary universities and human hospitals that focus on neurosurgery. Utilizing a hollow titanium tip that vibrates along its longitudinal axis, fragmentation of susceptible tissue occurs while concurrently lavaging and aspirating material from the surgical site. The CUSA selectively ablates tissues with high water content such as liver parenchyma, glandular, and neoplastic tissue.  This instrument is most useful when removing purportedly “non-resectable” brain and spine tumors. With a gentle wand-like motion, the CUSA enables a “layer by layer” surgical excision without affecting vital structures.

**HISTORY**

Daniel Bernoulli, an eighteenth-century Swiss scientist known for his work in heterodynamics, stated that when the velocity of fluid increases, its pressure decreases. According to Bernoulli’s law, when a high speed water jet stream is generated, the pressure within the stream drops so low that the water vaporizes. This process is called “cavitation”.

In 1916, the physicist Lord Rayleigh discovered the effect of cavitation while investigating damage to a ship’s propeller. He concluded that the collapse of the bubbles created a small jet stream of water, which was responsible for the structural damage. Using a similar principle, high speed mechanical waves can be used in non-elastic media, such as water, to create a cavitation effect. If this phenomenon is applied to water-rich tissues, such as liver, the final effect is the destruction of all the cells, preserving structures rich in collagen (low in water), such as blood vessels, nerves and billiary ducts.

The cavitron ultrasonic surgical aspirator (CUSA) device generates ultrasonic waves in the range of 23 kHz to produce tissue cavitations. This mechanical energy is delivered through a hollow 3 mm tip that vibrates at 23,000 cycles per second. The entire device is embedded with an irrigator and aspirator in order to dispose of the tissue debris. Tissue damage can extend up to 2 mm and depends on the concentration of water and fat within the cell. In laparoscopic surgery, the ultrasonic cavitational aspirator has been successfully used in general surgery and gynecologic procedures, resulting in decreased blood loss, improved visibility and reduction in tissue injury.

**PHYSICAL TECHNIQUE AND MEDICAL BASIS OF ULTRASONIC SURGERY**

A soundwave is characterized by the amplitude, respective sound intensity (sound energy), the wavelength and the sound extension velocity c (c = 1450m/s in human tissue). Ultrasound has a frequency of f =20000 Hz, hence a short wave length, and depends more on the laws of optics than on the laws of acoustics.

The working frequency desired in conducting ultrasound, f=25 kHz is achieved with an oscillation amplitude of around 300 mm at a 15 mm2 big sound probe value of acceleration of around 10000 x g and intensities of 200 to 1000 mW/ mm2.

During the use of ultrasonic dissector power is transmitted from a longitudinal vibrating probe tip in the contact zone of biological tissue, especially by liquid cavitations. This causes a change of form condition in the symplasm.

The cell and tissue fragments can be collected by a probe with an integrated aspiration/irrigation device.

The tumor destroying effect of the ultrasound will be enhanced by the existing liquid cavitations. These cavitations are bound to a high colloidal water content of biological tissue and depends on the consistency and temperature of the medium and of the frequency and intensity of the ultrasonic vibration.

When exceeding the cavitations girder of about 30 mW/ mm2, cavity vesicles form in the parenchymateus tissue. These are imploding due to the great low pressure and their kinetic energy (pressure impact on a narrow limited space).

This has a destroying effect on the adjoining tumor cells Because of the spread of sound cavitations blow and the probe absorption at tissue parts with higher cavitations girders, it is not possible to form a homogeneously sound field.

The energy consumption process prevents the energy from extending into the depth of the tissue and therefore protects the fibrous tissue structures, vessel walls and nerve parts.

**COMPONENTS OF A TYPICAL CUSA PROBE**

The CUSA ShearTip is intended for surgical procedure where fragmentation, emulsification and aspiration of soft tissue is desirable, including Neurosurgery, Gastrointestinal and affiliated organ surgery, Urological surgery, Plastic and Reconstructive Surgery, General Surgery, Orthopedic Surgery, Gynecological Surgery, Thoracic Surgery, Laparoscopic Surgery and Thoracoscopic Surgery. The main components of the CUSA are as shown in Fig. 1.



Figure 1.  Neurosurgeons use a cavitron ultrasonic surgical aspirator (CUSA) to “cut out” brain tumors without adversely affecting the surrounding healthy tissue.

The CUSA probe consists of three distinct components:
• Transducer: A device that converts electromagnetic energy into mechanical vibrations. The transducer is composed of a stack of nickel alloy plates. A magnetic field is produced by a coil placed around the plates and causes mechanical motion of approximately 300 microns.
• Connecting body: Mechanically conveys the motions of the transducer to the surgical tip. It also amplifies the vibration motion of the transducer.
• Surgical tip: Completes the amplifications of the motion and also contacts the tissue. Hence tip is relatively long compared to its diameter and this provides adequate motion amplification.
- The electric coil which is permanently fitted in the hand piece surrounds the transducer.
- This coil receives 23,000 cycles per second (hertz) alternating electric current from the console and activates the transducer.
- The hand piece is connected to the console by a cable which includes the tubing for circulating fluid between the cooling water canister in the console and the hand piece.
- Since the electric coil has a current flowing through it heat is generated and absorbed by the water circulating within the hand piece.
- This keeps the hand piece at a comfortable temperature for the surgeon.

**MECHANICS OF CUSA OPERATION**

Tissue removal and damage occurs when the vibrating metal probe is brought into contact with tissue such that it is cut, dissected, fragmented, ablated or coagulated. The CUSA console provides alternating current (23 or 36 kHz) to the hand piece. In the hand piece, the current passes through a coil, which induces a magnetic field. The magnetic field in turn excites a transducer of nickel alloy laminations, resulting in oscillating motion in the transducer laminated structure—vibration—along its long axis. The transducer transmits vibrations through a metal connecting body to an attached surgical tip. When the vibrating tip contacts tissue, it breaks cells apart (fragmentation). The CUSA system supports both 23 and 36 kHz magnetostrictive hand pieces, and each supports multiple tip designs. The powerful 23 kHz hand piece fragments even tough, fibrous, and calcified tumors while the small; 36 kHz hand piece is helpful during procedures requiring precision, tactile feedback, and delicate control. A wide variety of tips enables customization of the hand piece for each procedure, depending on the consistency, location, and depth of the targeted tissue.



Fig. 2. Ultrasonic surgery is carried out with the aid of ultrasonic instrument known as the CUSA

As shown in Fig.2. the treatment goal is destruction or alteration of tissues in close proximity to the probe–tissue interface rather than propagation of vibratory energy in the tissues. The range or area over which clinically relevant ablation or fragmentation effects occur in these systems has not been elucidated.

The transformation of energy, which has to be limited to the smallest possible place, depends on the correct adjustment of ultrasonic intensity, tissue the exposure time, the suction pressure and the handling of instrument during the operation.

The transformation of energy can also be limited, because of the permanent decoupling of the ultrasonic from the surrounding tissue and the permanent aspiration of disintegrated tissue if the surgeon uses a “dabbing” working motion. Tumor removal will occur initially at the surgical site and not in any great depth. There is no thermal damage due to permanent aspiration during ultrasonic exposition of tissue (confirmed by histomorphological examination).



Fig. 3. CUSA effect of 24khz and 35kHz handpieces on the tissue

Handpieces operate at frequencies of either 24 kHz or 35 kHz. The 24 kHz handpieces generate more power, and their tissue effect is both broader and deeper. This makes them particularly efficient in the removal of large, dense, and/or calcified tumors. The 35 kHz handpieces have a less powerful, more focused, and more superficial tissue effect and are thus more suited for soft tissue areas adjacent to sensitive structures. All handpieces are CF (cardiac floating) rated. The use of different hand pieces make it possible to identify and isolate important vessels in the surgical site by tissue selection and to maintain those vessels if necessary. This advantage for the surgical procedure is very difficult to realize with other surgical techniques of tumor removal.

Vessels are mostly elastic than the surrounding tissue, and their mechanical breaking limit will not be achieved. The separation forces will be decreased 10-20 times during ultrasonic disintegration compared with conventional microsurgery cutting instruments. This leads to less trauma and mechanical alteration of surrounding tissue due to force and pressure applied. This avoids possible secondary complications.

**CAVITATION**

Cavitation is defined as the process of formation of the vapour phase of a liquid when it is subjected to reduced pressures at constant ambient temperature. Thus it is the process of boiling in a liquid as a result of pressure reduction rather than heat addition. Cavitation is now recognized as an important factor contributing to the success of numerous biomedical applications or as an inherent feature of ultrasonic processes. An oscillating acoustic pressure field, superimposed on the ambient pressure, is established around the distal-tip (Nyborg, 1996; Makin and Everbach, 1996).

Cavitation occurs when, on the negative side of a pressure cycle, such as when the probe-tip is retracting with sufficient amplitude and frequency, suspended gas bubbles either within fluid, tissue or trapped at solid interfaces expand and collapse resulting in the generation of shock waves. Ultrasonic cavitation bubbles have complex dynamic behaviour.

Fong et al. have experimentally studied the interaction of a cavitation bubble and adjacent biomaterial in an ultrasound field. They observed that cavitation bubble behaviour is highly sensitive to different types of biomaterial (Fong et al., 2006). They describe the interaction of cavitation bubbles with a range of biomaterials. When these bubbles collapse, jet-like ejection into the fluid occurs, with very high maximum velocity jets directed away from, or towards the biomaterial (700–900ms−1) (Brujan et al., 2001a,b). The bubble oscillates and either forms a jet or splits into two smaller bubbles.

Cavitation may have significant mechanical effects because of the violent nature of the rapid collapse of cavitation bubbles. Variable responses were observed for the biomaterial in contact with the jet ranging from minimal motion (cartilage, bone) to attraction of material towards the bubble (fat, cornea). Theoretical models have been proposed for pressures generated in cavitation jets when the bubble collapses close to biomaterials, resulting in fragmentation of brittle objects such as dental tartar or intraocular lenses (Brujan, 2004). This process aids destruction at the probe–tissue interface. Others suggest that cavitation bubbles at the probe tissue interface may lead to inefficient coupling of vibratory energy to tissue and reduce tissue processing efficiency (Cimino, 1999).

In clinical applications, it is unclear whether cavitation phenomena occur in intra-cellular, extra-cellular or surrounding fluid. This theory suggests that within tissue, cavitation causes cell fragmentation and destruction and, in contrast, cavitation occurring in the surrounding fluid causes inefficient coupling with energy dissipated and no cellular fragmentation. In the latter scenario, cavitation bubbles may be reflected back towards the probe in a linear jet and away from the tissue. This theory is supported by ‘pitting’ visualized in clinical practice at ultrasonic end-effectors (Cimino, 1999). An increased understanding of bubble dynamics in an ultrasound field near a biomaterial may stimulate future improvements in instrument design and execution of ultrasonic biomedical processes.

**SUCTION AND IRRIGATION**

The CUSA has a self-contained suction capability to remove fragmented tissue and irrigation fluid. Suction power is generated directly from the CUSA unit, and it ensures that the suction power is consistent and the maximum possible. Consistent, strong suction provides two major benefits in ultrasonic aspiration. First, it draws tissue toward the vibrating tip, and creates a tip/tissue coupling effect. Second, it keeps the surgical site clear of irrigation and fragmentation debris and minimizes blockage in the suction tubing. Irrigation fluid flows coaxillary around the outside of the vibrating tip to keep the tip cool and to suspend fragmented tissue in solution to minimize tip blockage. A clear, silicone flue encircles the tip and provides a continuous pathway for delivery of the irrigation fluid. The flue ends approximately 2 mm from the distal end of the tip and just covers the pre-aspiration holes.



Fig. 4. Detailed description of the active CUSA tip

The two 0.4-mm holes aspirate as much as 95% of the irrigation fluid back through the inside of the hollow tip before the fluid reaches the end of the tip and the surgical site. The pre-aspiration holes have several functions:

(1) Removing the heat generated by the rapidly vibrating tip to help prevent tip fracture and thermal tissue damage.

(2) Lubricating and suspending the fragmented tissue to prevent blockage in the suction line.

(3) Reducing the amount of irrigant delivered to the surgical site to eliminate the flooding and fluid bubbling that may interfere with visibility.

**CONCLUSION**

When ultrasonic waves are used in medicine for diagnostic purposes, high-frequency [sound](http://demo.webassign.net/ebooks/cj6demo/xlinks/kwd/index.htm?unit=u0024" \t "keywords) pulses are produced by a transmitter and directed into the body. As in sonar, reflections occur. They occur each time a pulse encounters a boundary between two tissues that have different densities or a boundary between a tissue and the adjacent [fluid](http://demo.webassign.net/ebooks/cj6demo/xlinks/kwd/index.htm?unit=u0017" \t "keywords). By scanning ultrasonic waves across the body and detecting the echoes generated from various internal locations, it is possible to obtain an image or sonogram of the inner anatomy. Ultrasonic imaging is employed extensively in obstetrics to examine the developing fetus. The fetus, surrounded by the amniotic sac, can be distinguished from other anatomical features so that fetal size, position, and possible abnormalities can be detected.

Ultrasound is also used in other medically related areas. For instance, malignancies in the liver, kidney, brain, and pancreas can be detected with ultrasound. Yet another application involves monitoring the real-time movement of pulsating structures, such as heart valves (“echocardiography”) and large blood vessels.

When ultrasound is used to form images of internal anatomical features or foreign objects in the body, the [wavelength](http://demo.webassign.net/ebooks/cj6demo/xlinks/kwd/index.htm?unit=u0023" \t "keywords) of the [sound](http://demo.webassign.net/ebooks/cj6demo/xlinks/kwd/index.htm?unit=u0024" \t "keywords) [wave](http://demo.webassign.net/ebooks/cj6demo/xlinks/kwd/index.htm?unit=u0023" \t "keywords) must be about the same size as, or smaller than, the object to be located. Therefore, high frequencies in the range from 1 to 15 MHz (1 MHz=1 megahertz=1×106 Hz) are the norm. For instance, the wavelength of 5-MHz ultrasound is l=v/f=0.3 mm, if a value of 1540 m/s is used for the speed of sound through tissue. A sound wave with a [frequency](http://demo.webassign.net/ebooks/cj6demo/xlinks/kwd/index.htm?unit=u0023" \t "keywords) higher than 5 MHz and a correspondingly shorter wavelength is required for locating objects smaller than 0.3 mm.

Ultrasound also has applications other than imaging. Neurosurgeons use a device called a cavitron ultrasonic surgical aspirator (CUSA) to remove brain tumors once thought to be inoperable. Ultrasonic [sound](http://demo.webassign.net/ebooks/cj6demo/xlinks/kwd/index.htm?unit=u0024" \t "keywords) waves cause the slender tip of the CUSA probe (see Figure [16.35](http://demo.webassign.net/ebooks/cj6demo/xlinks/c16-fig-0035.htm%22%20%5Ct%20%22_blank)) to vibrate at approximately 23 kHz. The probe shatters any section of the tumor that it touches, and the fragments are flushed out of the brain with a saline solution. Because the tip of the probe is small, the surgeon can selectively remove small bits of malignant tissue without damaging the surrounding healthy tissue.

Another application of ultrasound is in a new type of bloodless surgery, which can eliminate abnormal cells, such as those in benign hyperplasia of the prostate gland. Still in the experimental phase, this technique is known as HIFU (high-intensity focused ultrasound). It is analogous to focusing the sun’s electromagnetic waves by using a magnifying glass and producing a small region where the energy carried by the waves can cause localized heating. Ultrasonic waves can be used in a similar fashion. The waves enter directly through the skin and come into focus inside the body over a region that is sufficiently well defined to be surgically useful. Within this region the energy of the waves causes localized heating, leading to a [temperature](http://demo.webassign.net/ebooks/cj6demo/xlinks/kwd/index.htm?unit=u0018" \t "keywords) of about 56 °C (normal body temperature is 37 °C), which is sufficient to kill abnormal cells. The killed cells are eventually removed by the body’s natural processes.