# 3D SIMULATION OF ULTRASOUND PROPAGATION IN HUMAN SCULL

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**Summary:** *In this paper, the 3D computer simulation of ultrasound propagation in scull during neurosurgical treatments is described. Neurosurgery treatment of brain tumors often result with damage of healthy tissue so simulation is necessary. The simulation was carried out in three-dimensional space. The method of simulation is virtual source model, with calculation of important wave phenomena. The measurements were carried out on real scull, in order to check the precision of simulation.*
*The results of simulation are indicating the undesirably high level of ultrasound energy in the central part of temporal lobe. This can cause damage to healthy tissue of speech, motor and sensory functions.*
**Key words:** *ultrasound, computer simulation, neurosurgery*

## 1. INTRODUCTION

Ultrasound in medicine is often used for various diagnostic tools. These tools are using ultrasound of high frequency (>1 MHz) and low power levels. The principles of propagation and function of this type of ultrasound is well examined and described.
Although there are few, some surgical tools based on ultrasound also exist. These tools are used for the destruction of unhealthy tissue, primarily during neurosurgical treatments. Their name is CUSA (Cavitation Ultrasound Surgical Aspirator). CUSA is most often used for treatment of brain tumors. Although there are other kinds of neurosurgery treatments [12,13,1,2], CUSA is very efficient way of treating several kinds of brain tumors.
CUSA works on low ultrasound frequency of about 24,5 kHz. It emits ultrasound of high energy that propagates through surrounding brain tissue. During this propagation due to high energy this ultrasound causes destruction of tumor tissue. There are several phenomena that cause the destruction of tumor tissue. The first phenomenon is creation of lesions due to increase of tissue temperature caused by ultrasound energy. A second phenomenon is "hammer" effect that causes destruction of tissue.

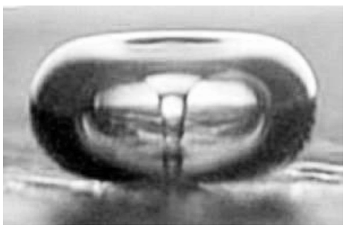

**Fig. 1.** Bubble caused by cavitation. In the middle of the bubble one can see vortex caused by the implosion.

A third and dominant phenomenon is cavitation (fig 1.). The cavitation is caused by rapid and extremely powerful changes in sound pressure caused by propagation of ultrasound in fluids. In places of extremely low pressure vacuum bubbles are created. Due to high frequency in the next moment at the same spot the sound pressure dramatically increases and causes the implosion of cavitation bubble. This causes high tension in fluid, and since the brain tissue can be regarded as fluid, this tension can cause destruction of tissue [3,10,3,4].
Due to these effects in the vicinity of CUSA the tumor tissue is destructed and aspirated through the aspirator. But since the CUSA transducer is omnidirectional, ultrasound propagates in other directions, not only in the direction of tumor. So, neurosurgery treatments of brain tumors often result with damage of healthy tissue. To discover the cause of the damage, it was necessary to make a simulation of the treatment.

## 2. PRINCIPLES OF SIMULATION

Due to practical and ethical reasons the computer simulation was chosen instead of simulation on a model. The computer simulation is always a kind of compromise between the complexity of phenomena related to the propagation of ultrasound and the computational power (processor time) that can be used. So, in the first phase, the two-dimensional simulation was carried out and was checked by measurements on the model [9,5].
To get more accurate results it was a must to make a 3D simulation in which the propagation of sound in three dimensions would be calculated. This simulation was programmed in Discreet 3D Studio MAX 3.0 visualization software. The used computer language was MaxScript. This choice also made possible the visualization of neurosurgical treatments.
The simulation was based on the virtual source method [4,5,8,9,11,6,7,8,5,9]. This method was chosen in favor of ray-trace, FEM and BEM methods because of its accuracy. The geometry of ultrasound rays is calculated by mirror image of sources (fig 2.)

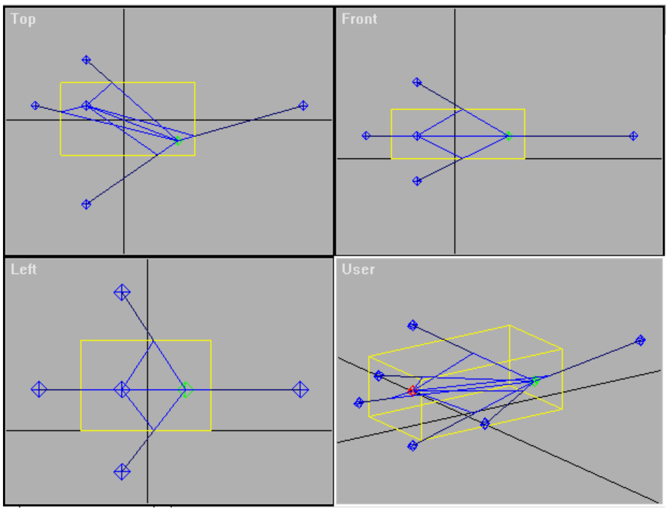


**Fig. 2.** Virtual source method: Red diamond is source, blue diamonds are virtual sources, and green diamond is receiver.

Due to propagation of ultrasound the amplitude and frequency of ultrasound is changed. The amplitude of sound is changed due to propagation, absorption in media and reflection from bones. The phase of sound is changed because of propagation and reflection. To calculate the amplitude and phase of the sound it was necessary to know acoustic parameters of brain tissue: the velocity of sound, the absorption of sound in brain and the specific acoustic resistance. These parameters are well known on high ultrasound frequencies that are used in diagnostic tools. On the working frequency of CUSA, these parameters were not published, so measurements were necessary [1,2,10,10,11,4]. Table I shows the measured parameters:

| | |
|---|---|
| Velocity | c=1528 m/s |
| Apsorption | $\alpha$ = 0.44 dB/cm |

**TABLE I** The parameters of ultrasound propagation in brain tissue for f=24,5 kHz, and T=20°C

The input parameters of simulation for the specific neurosurgery treatment are the TIN (triangulated irregular network) grid of patient scull, and the position of CUSA transducer. In order to obtain TIN, the CT scan has to be made. The slices from CT scan are than digitized, positioned in space and transformed to TIN grid (fig. 3).

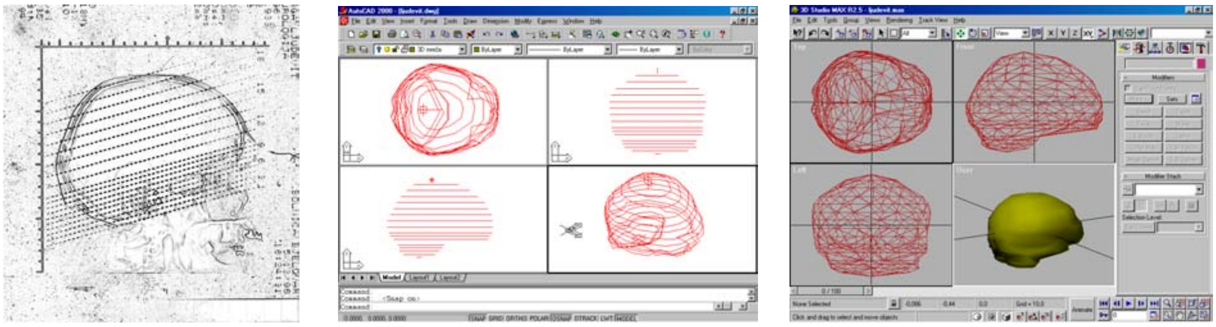

**Fig. 3.** CT scan of patient's scull (left), digitized slices (middle) and TIN gird of scull (right).

After the data is entered, the simulation can be carried out. The simulation has two forms of output. The first one displays the position of virtual sources and the trajectories of sound waves (fig. 2). The second one displays the SPL (Sound Pressure Level) in different colors, ranging from black for the low SPL, red for middle SPL, and white for high SPL. The SPL are displayed for slices of brain whose position can be adjusted as needed.
To check the accuracy of the simulation, measurement on real scull was carried out. The simulation and measurement were made for 9 points inside the scull. The comparison of the result showed that expected accuracy is 3 dB, which is satisfactory for the purpose of the simulation.

## 3. SIMULATION OF TUMOR SURGERY

During neurosurgical treatment of brain tumors healthy tissue is often damaged. This causes malfunction of some of the brain centers, and severe defects for patient. This was the main reason for developing the simulation, so the simulation of real world neurosurgical operation was carried out. Typical treatment with CUSA is the treatment of an eye-neuron tumor. This tumor is situated in the temporal lobe of the left hemisphere of brain. The scull of the patient was modeled from CT scan, and prepared for simulation. The results of the simulation are shown in figure 4.

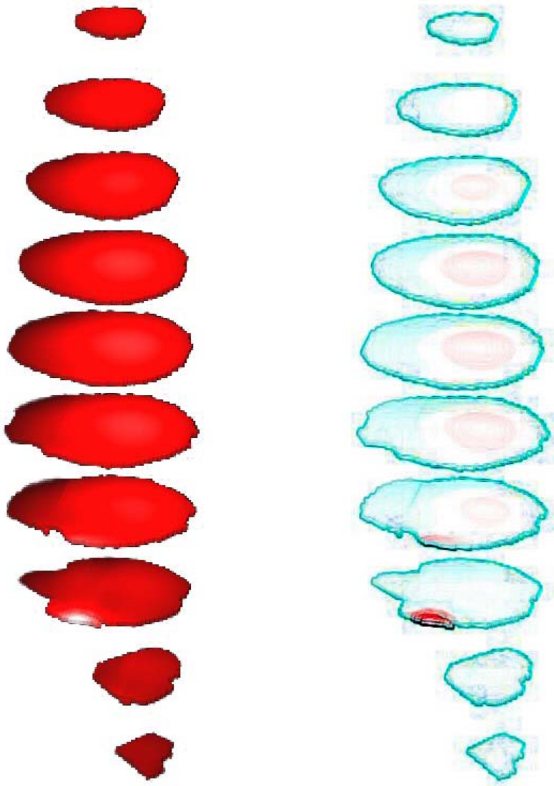

**Fig.** The results of the simulation: original – left, Adobe Photoshop Find Edges filter – right

The CUSA entered scull in the part where the tumor is located. In this part the white spot in the figure 4 indicates the highest ultrasound energy. This energy is spent on the destruction of tumor tissue that is then aspirated. The SPL of ultrasound is decreasing as propagated through the brain, which is evident by the darker tones of red color around the tumor. But in the central part of the parietal lobe a spot of brighter red colors is indicated. This means that there is high SPL, which can cause damage to brain tissue. The cause for this is the reflection of ultrasound from the top of the scull. This part of the scull is curved, so it functions as a concave mirror, and focuses the ultrasound to the spot of higher SPL. In the part of the brain where this higher SPL is indicated - the central part of the parietal lobe – there are situated several important centers such as: speech, motor and sensory function centers. In real neurosurgical treatments this centers are damaged, and some functions are lost.

## 4. CONCLUSION

The simulation of the neurosurgical treatment of brain tumor showed that although the greatest part of the energy is spent on destruction of tumor tissue, the SPL is higher than normal in the central part of parietal lobe. This effect is not welcomed because in this part of brain healthy tissue is situated. The reasons for this are the focused reflections from the top of the scull. Since the brain centers for speech, motor and sensory functions are located at this position, they are often damaged during the treatment.

In given conditions it is not possible to make a transducer with directional characteristic that would focus energy on the tumor, and not dissipate it in the rest of the brain. Thus, alternative approach must be taken. It is necessary to make simulation of every single operation, and in cooperation with neurosurgeon, to make an approach plan which would reduce the risk for patient. With carefully chosen path of approach and control of level of radiated energy, the unwanted side effects of treatment would be reduced.

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## TRODIMENZIONALNA SIMULACIJA ŠIRENJA ULTRAZVUKA U LJUDSKOJ GLAVI


**Sažetak:** *U ovom radu predstavljena je trodimenzionalna kompjuterska simulacija širenja ultrazvuka u glavi za vrijeme neurokirurških operacija. Ovakva simulacija je nužno potrebna jer neurokirurške operacije tumora mozga često rezultiraju oštećenjima zdravih centara u mozgu. Simulacija se odvija u trodimenzionalnom prostoru, pomoću metode virtualnih izvora, uzevši u obzir sve relevantne valne fenomene. Zbog provjere rezultata izvršena su mjerenja na stvarnoj lubanji.*

*Rezultati simulacije ukazuju na nepoželjno izdizanje razine ultrazvučne energije u centralnom dijelu zatiljnog režnja. Ova pojava može uzrokovati oštećenja centara za govor, motoriku i osjet.*



**Key words:** *ultrazvuk, kompjuterska simulacija, neurokirurgija*