日立メディコ 技術研究所　窪田 純

IV. 資料 [Abstracts]

[Ab1] Session: 1J　THERAPEUTICS　1J-1 1:30 p.m.

A 500 ELEMENT ULTRASOUND PHASED ARRAY SYSTEM FOR NONINVASIVE FOCAL SURGERY OF THE BRAIN- A PRELIMINARY RABBIT STUDY WITH EX VIVO HUMAN SKULLS

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Purpose: To test a prototype Magnetic Resonance Imaging (MRI) compatible focused ultrasound phased array system for trans-skull brain tissue ablation using ex vivo human skulls and an animal model. Methods: Rabbit thigh muscle (N=3) and brain (N=10) were sonicated with a prototype, hemispherical 500-element ultrasound phased array operating at frequencies between 700 and 800 kHz. An ex vivo human skull sample was placed between the array and the animal tissue. The temperature elevation during 20-30 s sonications were monitored using MRI thermometry. The induced focal lesions were observed in T2 and contrast-enhanced T1-weighted Fast Spin Echo images. Whole brain histology evaluation was performed after the sonications. Results: Sharp temperature elevations were produced both in the thigh muscle and in the brain. The temperature elevations per applied acoustic watt during 20 s sonications in the thigh muscle and brain were 0.04+/- 0.03C and 0.022 +/- 0.010C, respectively. The high power sonications (600 - 1080 W) produced peak temperature up to 55C and focal lesions that were consistent with thermal tissue damage. The lesion size was found to increase with increasing peak temperature Conclusions: This study demonstrates that it is possible to create ultrasound-induced lesions in vivo through a human skull under MRI guidance with this large-scale phased array device.

[Ab2] Session: 1D　EMBOLI DETECTION/CONTRAST AGENTS　1D-1 8:30 a.m. (Invited)

ULTRASONIC DETECTION OF CEREBRAL EMBOLI

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It is now generally believed that the majority of strokes are caused by emboli from distal sites, rather than by local haemorrhagic or occlusive processes. The discovery that emboli of various types can be detected using Doppler ultrasound as they are carried through the major cerebral arteries has led to a new field of study, which appears to have considerable potential both in research and clinical settings. The basic principle of detection is extremely simple: if an embolus back-scatters more power than the surrounding blood in which it is moving, then the transitory increase in power can be detected and measured. Questions that arise from this principle surround the circumstances under which such power increases can be detected, and whether the size and composition of the embolus can be inferred from such measurements. The detectability of an embolus is determined by many factors including its size and composition, the ultrasound frequency, the size of the Doppler sample volume, the embolus trajectory and its

interaction with the ultrasound beam. In general even relatively small gas bubbles will be detected, but some larger solid emboli may be missed. With regard to size and composition, several techniques have been suggested as being useful for characterising composition, and whilst in general considerable progress has been made in this direction there are still many challenges in distinguishing between large particulate emboli and small gaseous emboli. Unfortunately the sizing of emboli remains a distant goal.

[Ab3] Session: 3K TRANSDUCER MATERIALS II 3K-3 5:00 p.m.

EFFECT OF MATCHING LAYER ON ACOUSTIC LENS SUPPRESSING LAMB WAVE FORMATION

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A matching layer on a lens is a common practice in optics, but it is not widely used in acoustics. One of the reasons may lie in that materials for a lens with good acoustic matching with water and human tissues are available at 1-10 MHz. Most of these materials are polymers with a speed of sound significantly lower than water and tissues. They may not be appropriate for diagnostic transducers at an extremely high frequency or therapeutic transducers because of their acoustic attenuation higher than tissues by an order of magnitude. Light metals such as aluminum have a sufficiently high speed of sound and a low attenuation, but they have poor acoustic matching with water and tissues. It is evident that transducers with variable focal length are useful for therapeutic as well as diagnostic application of ultrasound. They are especially useful for intracavitary therapeutic application to avoid the necessity of using plurality of transducers with different focal lengths, which significantly elongates the therapeutic session. Prototype therapeutic linear array transducers at 3.5 MHz, with an aluminum lens for elevation focusing, were designed for transrectal treatment It had an elevation width of 21 mm. The cylindrical lens with a thickness of approximately half a wavelength, directly attached to PZT on the other side, had an acoustic matching layer made of epoxy resin containing tungsten powder. Numerical simulation of wave propagation was performed using a finite element code, PZFlex, with and without the acoustic matching layer, for cylindrical curvature radii of 38 and 60 mm. The comparison of the results clearly showed the effect of matching layer to suppress Lamb wave formation in the lens. The matching layer reduced the level of unwanted side lobes, arising from the Lamb waves, from -13 dB to -21 dB and -6 dB to -22 dB for a curvature radius of 38 and 60 mm, respectively, at the focal plane. Prototype variable focal length transducers with and without a matching layer were then fabricated and tested. Canine prostate was transrectally treated and successfully coagulated with the transducer with a Lamb-wave-suppressing matching layer on the lens 38 mm in radius.

Concept of Ultrasound Cerebral Infarction Therapy Equipment for Early Dissolution of Thrombus

Jun Kubota 1), Akira Sasaki 1), Makoto Ogihara 1), Takashi Azuma 2), Shin-ichiro Umemura 2), Hiroshi Furuhata 3)

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Abstract

We develop equipment for cerebral infarction therapy, which is comprised that ultrasound is illuminated on embolized part of a brain trans-cranially with injection of thrombolytic agent. Minimizing the thermal and mechanical bio-effect of therapeutic ultrasound, its frequency band is selected between 500-800kHz, where Thermal Index, that indicates an increase of tissue temperature, TI=<2, and Mechanical Index (MI), that MI=1 indicates threshold of possibility of causing cavitations in human body, equal to or less than 0.25. The equipment emits therapy and diagnostic beams alternately whose output level and intermittent duty ratio are controllable through modulation. The results of computer simulation and basic experimental data of therapy/diagnostic compound transducers, which are nearly equally work as separate transducers, are described. It is expected that the system lower the fatality rate of the stroke patients, improve the prognosis, and contribute to decrease health care cost.

1. Introduction

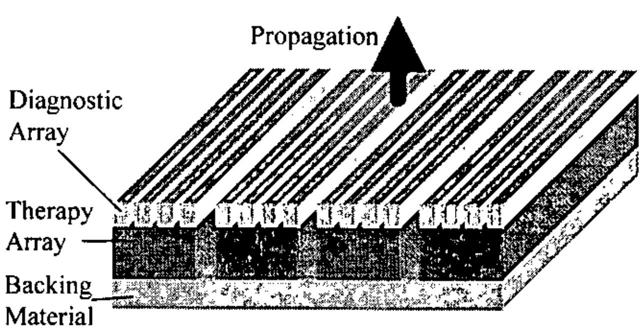

Fig.1 Structure of the Dual-frequency Transducer

Cerebrovascular accident (CVA) is the third largest cause of death in Japan. Cerebral infarction (CI) dominates 70% of the CVA, and often leaves allophasis or paralyses after the recovery, and might increase the number of elderly people who need nursing care. We develop equipment for CI therapy, that make up over 60% of cerebrovascular disorder, from which large number of people die every year, the next to cancer and cardiovascular disease. The equipment is comprised that ultrasound is illuminated on embolized part of a brain trans-cranially with injection of thrombolytic agent so that blood clot in cerebral artery should dissolve in early time from the injection, be rapidly recanalized, and relieve cerebral nerve system that is destructible from ischemia. To treat CI, it is the first choice to dissolve thrombi or emboli that is the principal cause in a few hours from sideration. It is said that the earliest disobliteration will promise good prognosis Furuhata et al.[1][2] published in vitro and vivo experiment results. This study aims to develop a trans-cranial ultrasonic cerebral thrombolysis system to study usefulness of the technique clinically applicable for various disease pattern of CI explanatorily.

2. System configuration

As a fundamental concept, we propose a monitoring to dissolution feedback therapy method, combining medication decrease and side-effect suppression. To realize it, therapy and diagnosis combination probe is needed, since the acoustic window apertures are restricted to two to three cm square in the cranial bone. Therapy transducer needs a large aperture to transmit 500 kHz beam to a limited region of infarction, and diagnostic transducer also needs a large aperture to acquire precise images with 2 MHz beam. Transmitting circuit drives the transducer to emit 500 kHz T-beam of less than 0.72 W/cm2 in intensity, and 2 MHz D-beam of the same intensity level intermittently. The system also has a feature of two-dimensional deflection of the beam to confine the irradiating region. Fig.1 shows the configuration of the therapy-diagnostics laminated probe where the D-beam transducer is formed over the T-beam transducer held on a backing material.

2.1. Simulation

Fig.2 shows the simulation model of the complex transducer, which is made up of materials of the backing material, the therapy transducer (array), separating layer, diagnostic transducer (array), and two matching layers.
Both the D/T-laminated and D-beam single layer array vibrating system are simulated, using PZFlex piezo-mechanical finite element analysis code, driving single element of the array.

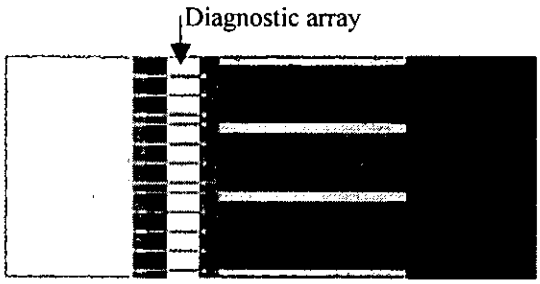

Fig.2 Piezo-acoustic analysis of the dual frequency transducer

2.2. Basic experiments

Normal single layer array works as Fig, 3, when a single element of the array is driven by a continuous wave of 2 MHz, where wave front from a common point source can be seen, as an instantaneous propagating mode of operation.

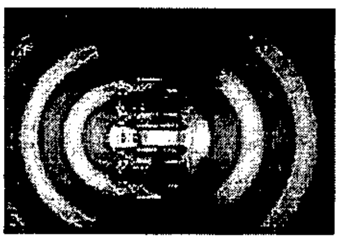

Fig.3 Simulated wave front emit from a single element of a single layer diagnostic transducer

Fig.4 Simulated wave front emitted from a diagnostic element of the dual frequency transducer

The complex dual frequency array operates as Fig. 4 when a single element of the D-beam array is driven by cw of the same frequency. Wave front is different propagating in the backing direction, meanwhile it is almost the same as the single layer array when propagating in front.

On the other hand, the same array operates as Fig. 5, when a single element of the T-beam array is driven. While the limitation of irradiation angle from the point source is shown, when comparing the wave front propagating from front face and backing side, it suggests that it is possible to deflect T-beam to somewhat large angle direction from the front face.

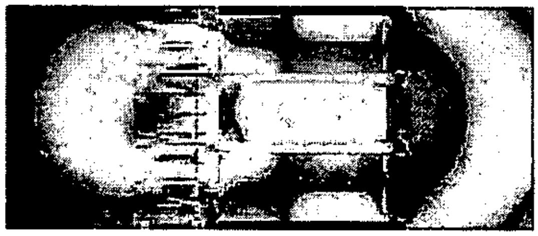

Fig.5 Simulated wave front emitted from a therapy single element of the dual frequency transducer

3. Results and discussion

T-beam propagation pattern through and in the cranial bone is observed in water with Schlieren technique although not shown here. Interference pattern is observed in the vicinity of the opposite concave reflection plane. That suggests the standing wave may build up, and could generate bubble via cavitation effect in the brain where Mechanical Index is as high as one regionally and stationary.

4. Conclusions

Therapy and diagnostic dual frequency multi layer ultrasound transducer is developed for Cerebral Infarction therapy by simultaneous use of trans-cranial ultrasound and thrombolysis agent, monitoring blood recanalization by TC color flow imaging. Preliminary experiments suggest that more sophisticated driving technique is needed than simple continuous wave.

5. Acknowledgements

This Research is supported by Japanese Ministry of Health, Labour and Welfare.

6. References

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[2] Akiyama M., Ishibashi T. et al., "Low-frequency ultrasound penetrates the cranium and enhances thrombolysis in vitro", *Neurosurgery, Vol. 43(4), Oct 1998, pp.828-32;* discussion *pp. 832-3.*

[3] Azuma, T., Umemura et al., "Dual frequency array transducer for ultrasound-enhanced transcranial thrombolysis", *IEEE 2003 Ultrason. Symposium Proc., to be published.*

第77回日本超音波医学会(H16年5月17－19日、於栃木県総合文化センター)予稿

血栓の早期溶解を目指した診断治療超音波複合プローブの原理試作

Trial production of diagnostic and therapeutic compound ultrasonic transducer for early dissolution of thrombosis

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【はじめに】　脳血管障害は、癌、心臓疾患に次いで死者数の多い疾患であり、そのうち脳梗塞疾患は6-7割を占める。我々は脳血栓塞栓症患者に血栓溶解剤静注投与と併用して経頭蓋的に超音波照射し、脳血栓の早期溶解、急速再開通を行うことで虚血耐性に脆弱な脳神経系を救出するシステムの開発を行っている。

【超音波脳梗塞治療装置】　本システムは経頭蓋超音波診断レベルの血流画像を取得し再開通監視を行うことにより、脳血管の再開通状態を確認し、溶解剤投与量を制御することができ、更に治療超音波(T)ビームの照射方向を3次元的に制御し照射範囲を患部周辺に限定することにより、脳組織内での出血に対する危険を避けることを可能とする。Tビームには、熱的及び機械的生体影響を最小とするため診断レベルでの超音波の体温上昇の指標であるTI値をTI≦2、かつ、キャビテーション閾値であるMI=1の1/4となるMI≦0.25の両者を満たす周波数帯域である300-800 kHzを採用した。また、再開通状態の監視を行うためTビーム照射と画像診断(D)とは交互に実施する系とし、照射されるTビームの出力レベルと間欠時間との制御を行うシステムとした。一方、Dビームは通常のTCDと同等の2 MHzとし、頭蓋骨の限られた音響窓を有効に活用して限局照射するため、T/D両ビーム用のトランスデューサは振動素子アレイを積層とすることによって音響窓を共有する構造とした。

【積層型プローブの試作】　本研究では、超音波治療システムについて、特にシミュレーション予測に基づいてプロトタイプを試作したので報告する。試作したプローブの外観をFig.1に、アレイの構造をFig.2に示す。厚さの異なる2枚の振動子（T及びD用）がバッキング材の上面にT,Dの順で積層されている。また、Fig.3では今回試作したプローブにおいて中心周波数400 kHzにて超音波を表面より50 mmの距離に収束させた際の音場分布を長軸、短軸それぞれ測定した結果を示す。半値幅はそれぞれ11.8 mm, 17.4 mmとなり、所期の動作を確認した。

本装置の臨床応用により、脳梗塞患者の死亡率低減、予後の改善、更には医療費削減への寄与が期待される。〔本開発は一部、厚生労働科学研究費補助金（基礎研究成果の臨床応用推進研究事業H14-トランス-016）による。〕

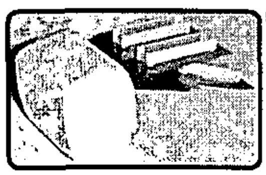

Fig.1 Photo of the T/D Combination Probe

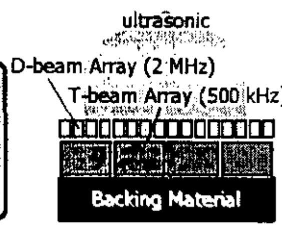

Fig.2 Structure of the Dual-frequency Transducer

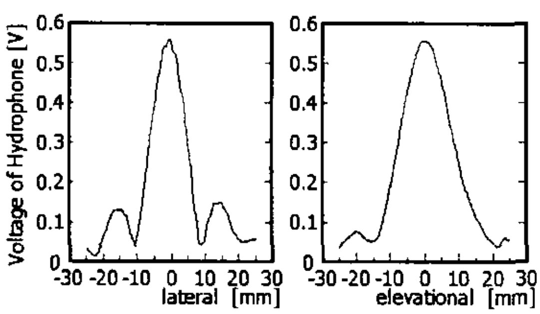

Fig.3 Beam pattern on the focal plane of z = 50 mm

第23回日本脳神経超音波学会(2004年6月3-4日, 久留米石橋文化センター)抄録

超急性期脳梗塞治療に向けた経頭蓋超音波脳血栓溶解装置の試作

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【背景】Translational 研究開発の一環として超急性期脳梗塞治療のための経頭蓋超音波脳血栓溶解装置を開発中である。これは脳血栓・塞栓症患者に血栓溶解剤投与と併用し、塞栓部に超音波照射することで脳血栓の早期溶解、急速再開通を行うものである。【開発内容】脳組織内での出血のリスクを低減するため、治療超音波(T)ビームの照射方向を調整し、照射範囲を患部周辺に限定する。使用するTビームは、熱的及び機械的生体影響を最小とするため、超音波による体温上昇の指標となるTI値をTI≦2、かつ、キャビテーション閾値の1/4となるMI≦0.25を満たし最大の許容出力余裕を得る周波数として約500kHzを採用した。再開通状態の監視を行うため、Tビーム照射と画像診断(D)とを交互に実施する系とし、照射されるTビームの出力レベルと間欠時間との制御を行うシステムとした。一方、Dビームは通常のTCDと同等の2MHzとし、頭蓋骨の限られた音響窓を有効に活用して限局照射するため、T/D両ビームの電子制御用の振動素子アレイを積層することによって音響窓を共有する構造とした。【結果】試作した超音波装置プロトタイプを用い、vitro及び健全動物試験を通じ、システムとして所期の目的を達成した。今後、安全性確認後、臨床適用を目指す。本研究は、厚生労働省科学研究費補助金「基礎研究成果の臨床応用推進事業」によって実施された。

第23回日本脳神経超音波学会(2004年6月3-4日，久留米石橋文化センター)抄録

超急性期脳梗塞治療に向けた経頭蓋超音波脳血栓溶解装置の試作

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Standing-Wave Formation in Water Surrounded by Cranium Radiated from 500 kHz Ultrasonic Sector Probe

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The use of ultrasound at a relatively low frequency, typically lower than 1 MHz, which can penetrate a skull bone more efficiently, are suitable to enhance the effect of thrombolytic drugs such as tissue plasminogen activator. Acoustic cavitation can cause adverse biological effects through inducing huge mechanical stresses and generating chemically active species. The generation of cavitation is affected not only by acoustic intensity and frequency, but also other conditions of an acoustic field, especially standing wave formation. In this study, standing-wave formation in water surrounded by a contoured piece of a human cranium with a transcranial ultrasonic beam at 500 kHz was optically observed using Schlieren imaging. The ultrasonic beam was generated from a prototype sector-scan phased-array transducer, which can a transmit ultrasound beam in various angles, with a fixed transducer position on the skull bone. The standing waves patterns were clearly seen near the places of reflection in the Schlieren images at certain beam angles. No standing wave patterns were detected in the basically the same setup with a commercial sector-scan phased-array transducer at 2 MHz. These suggests that standing waves can also be formed in the brain tissue near the place of reflection by transcranial insonation of a human brain at a relatively low ultrasonic frequency, typically less than 1 MHz, and further suggests the possibility of inducing the intracerebral hemorrhages through cavitation in brain tissue thereby. In order to suppress standing wave formation, modulations in ultrasonic frequency, amplitude, and beam angle should be studied to achieve efficient transcranial thrombolysis.

頭蓋内超音波音場のシュリーレン観測

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数100kHz域の超音波の印加によりtPA（tissue plasminogen activator）等の血栓溶解剤の効果が増強することが、動物実験により明らかにされている[1]。しかし、超音波の強度があるレベルを超えると、キャビテーション作用などにより、脳組織に損傷を与える可能性がある。キャビテーションは進行波よりも定在波によって、より生じやすいことが知られている。このため、頭蓋内の超音波音場の様子を把握することは重要であるが、これまで観測が行われたことがなかった。特にDaffertshoferらにより、300kHzの経頭蓋骨超音波照射治療において、脳内で出血が生じた事例が報告されており、頭蓋内超音波音場を把握することの必要性が高まっている。

今回、図1(a)に示すように、頭蓋骨を帯状に切断し、切断面の法線方向と光軸を平行にして、頭蓋骨を水中に固定。頭蓋骨の外側から500kHzの超音波を照射する配置により、頭蓋内水中音場のシュリーレン測定を行なった。図1(b)にシュリーレン像を示す。トランスデューサから頭蓋骨を透過した超音波は、反対側の骨の内側で、一回目の反射をしており、この反射部分近傍において定在波パターンが観測された。またこの反射波は更に、別の場所で反射して、元の入射波と、頭蓋の中央近傍でビームが交差して、干渉パターンが生成していることも観測され、シュリーレン法によって、頭蓋内超音波音場が複雑な様相を示すことが解った。

定在波音場の生成からキャビテーションの生成に至るには一定の時間が必要である。ビームの走査や、周波数変調、パルスシーケンスなどにより、定在波の生成を抑制し、キャビテーション生成の確率を低減することが可能と考えられる。発表においては、現在開発中のドップラモニタリング付アレイ型治療用超音波プローブを用いた、各照射方式による音場への影響に関する評価結果に関しても議論を行なう。

[1] T. Ishibashi, M. Akiyama, H. Onoue, T. Abe and H. Furuhata, *Stroke*, vol. 33, pp.1399-1404, 2002.

血栓溶解治療用トランスデューサから照射される

頭蓋内超音波音場のシュリーレン観測

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［目的］

数１００kHz域の超音波照射により血栓溶解剤の効果が増強することが、動物実験により明らかにされている[1]。このとき、キャビテーション作用による組織損傷を避ける必要があるが、定在波音場では気泡が定在波の腹に集積し、キャビテーション核になるため、進行波に比べ、キャビテーション閾値が低下する。このため、頭蓋内音場を把握する必要がある。

［方法］

シュリーレン法は波の伝播に伴う媒質の屈折率変化を可視化する方法である。頭蓋骨を鉢巻状に切断し、切断面の法線方向と光軸を平行にして、頭蓋骨を水中に固定。頭蓋骨の外側から500kHzの超音波を照射、頭蓋内水中音場を可視化した。

［結果］

頭蓋骨内で超音波は、反対側の骨の内側で反射、反射部近傍にて定在波パターンが観測された。定在波の生成からキャビテーションに至るまで数サイクル以上の超音波照射が必要なので、時間変調などの方法でキャビテーション抑制を検討する必要があることが解った。

［謝辞］

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[1] T. Ishibashi, M. Akiyama, H. Onoue, T. Abe and H. Furuhata, *Stroke*, vol. 33, pp.1399-1404, 2002.

500kHz 血栓溶解／2MHz ドップラ血流画像撮像用 積層型アレイトランスデューサの開発

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経頭蓋超音波血栓溶解治療においては、治療の効果と出血のリスクはトレードオフの関係にあるため、溶解剤の投与量や超音波照射時間、出力を制御するためには、頭蓋内血流モニタを用いた治療制御が必須である。しかし、治療用の周波数は、温度上昇や機械的作用の観点から数 100kHz 域が適しており、撮像用には、頭蓋骨透過率と空間分解能の点から 2MHz が適している。この大きく異なる二つの周波数を一つの圧電素子の周波数帯域内に含めるのは困難である。音響窓がこめかみに空間的に限定されている経頭蓋超音波照射には、二つの圧電素子を並べることも実用的ではない。我々はこの課題に対し、治療用と撮像用の二つの素子アレイを積層した構造を提案し、試作による動作確認を行った結果を報告する。圧電素子を積層すると、互いの相互作用により、各層の独立動作が困難である。新規に周波数選択性の分離層を各層の間に積層することで、各層の独立動作が可能であることをシミュレーションで見出し、構造の最適化を行った。この構造に沿って従来の撮像プローブと同サイズの試作を行った。治療アレイからは出力 0.5W/cm、500kHz、±45 度の範囲で電子走査可能なビームが送波可能であり、撮像アレイから、従来の撮像専用アレイと遜色のない血流画像が撮像可能であることを確認した。本研究の成果の一部は厚生労働省のトランスレーショナルリサーチの補助金を受けて実施したものである。

Dual Frequency Array Transducer with Bilaminar Structure for Ultrasound-Enhanced Transcranial Thrombolysis

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It is known that ultrasound can enhance thrombolysis with tissue plasminogen activator (tPA). An optimum control of the tPA injection and the therapeutic sonication require a blood flow monitoring. Ishibashi et al. reported that an ultrasonic frequency of approximately 500 kHz was most effective for recanalization of a rabbit's artery through a human temporal bone. However, this frequency is too low for ultrasonic blood flow imaging. Therefore, respective use of two frequencies for ultrasound-enhanced thrombolysis and ultrasonic imaging would be ideal. Since only a temple is the available acoustic window for transcranial ultrasound, the total aperture size for imaging and therapy is very limited. In order to expose ultrasonic waves at two frequencies for imaging and therapy from the same aperture, we propose a probe consisting of a therapeutic array with an imaging array overlaid on it. Between these two arrays, a frequency selective isolation layer was inserted to ensure independent oscillatory motions of the two arrays. The function of this layer is expected to reflect the waves from the imaging array and allow the waves from the therapeutic array to pass through.

Numerical simulation was performed using a finite element code, PZFlex. In this model, the imaging and therapeutic array used PZT ceramic with a center frequency of 2 MHz and 500 kHz, respectively. The imaging array had two acoustic matching layers. Several different thicknesses of the frequency selective isolation layer made of epoxy resin were tested. These results showed that the isolation layer with 50 micro-meters reduced the amplitude of the imaging pulse waves at 2 MHz reflected at the therapeutic array by 13 dB, while it reduced the amplitude of the therapeutic waves at 500 kHz only by 2 dB.

A prototype array transducer was constructed according to this analysis. Its experimental results; the pulse responses of the imaging layer, the Schlieren beam patterns radiated from the each layer and the tissue phantom images taken by the imaging array will be presented. This Research is supported by Japanese Ministry of Health, Labour and Welfare.

DUAL FREQUENCY ARRAY TRANSDUCER FOR ULTRASONID-ENHANCED TRANSCRANIAL THROMBOLYSIS

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Abstract – It is known that ultrasound can enhance thrombolysis with tissue plasminogen activator (tPA). A blood flow monitoring is required for an optimum control of the tPA injection and the therapeutic sonication. In order to transmit ultrasonic waves at two frequencies for imaging and therapy from the same aperture, we propose a probe consisting of a therapeutic array with an imaging array overlaid on it. Between these two arrays, a frequency selective isolation layer was inserted to ensure independent oscillatory motions of the two arrays. The function of this layer is expected to reflect the waves from the imaging array and allow the waves from the therapeutic array to pass through.

Numerical simulation was performed using a finite element code, PZFlex. In this model, the imaging and therapeutic array used PZT ceramic with a center frequency of 2 MHz and 500 kHz, respectively. An epoxy resin isolation layer with 50 micro-meters reduced the amplitude of the unwanted response at 2 MHz by 13 dB, while it reduced the amplitude of the therapeutic waves at 500 kHz only by 2 dB.

I. INTRODUCTION

It is known that ultrasound can enhance thrombolysis with tissue plasminogen activator (tPA) [1]. A blood flow monitoring is essential to optimize the amount of tPA bolus and the duration and magnitude of therapeutic sonication. Ishibashi et al. found that an ultrasonic frequency of approximately 500 kHz was most suitable for recanalization of a rabbit's artery through a human temporal bone [2]. In a higher frequency range, heat damage is not ignored. In a lower frequency range, the damage in brain caused by cavitation effects may be not ignored.

However, the frequency of 500 kHz is too low for ultrasonic blood flow imaging. Therefore, respective use of two frequencies for ultrasound-enhanced thrombolysis and ultrasonic imaging would be ideal. A diploe layer in a skull bone disturbs propagation of ultrasound waves [3]. But a temple includes thin or no diploe layer, and can be used as an acoustic window. Because of this reason, the total aperture size for the transcranial therapy with ultrasound monitoring should be limited to the size of a tmeple.

In this study, the structure of a probe consisting of a therapeutic array and an imaging array overlaid on it, was investigated. By using this structure, ultrasonic waves at two frequencies for imaging and therapy can be transmitted through the same aperture. Numerical simulations were used to estimate the oscillation modes in the two arrays; the impulse response in the imaging array and the transmission efficiency of the therapeutic array.

II. FREQUENCY SELECYIVE ISOLATION LAYER

In order to ensure independent oscillatory motions of the two arrays, between these two arrays, a frequency selective isolation layer was inserted. The function of this layer is expected to reflect the waves from the imaging array and allow the waves from the therapeutic array to pass through. The thickness and acoustic impedance of the layer was optimized for this function.

The model for numerical simulation was shown in figure 1. The numerical simulation was performed using a finite element code, PZFlex. In this model, the imaging and therapeutic array used PZT ceramic with a center frequency of 2 MHz and 500 kHz, respectively. The imaging array had two acoustic matching layers. Requirements for this layer were the isolation at 2 MHz and the transparence at 500 kHz. If thickness of the isolation layer was quarter of the wavelength at 2 MHz, two imaging pulses, which reflected at the front and back of the isolation layer, were synchronized, and the amplitude of synthesized pulse increased. On the other hand, this thickness was so thin for therapeutic waves that it did not disturb that propagation. In order to confirm this idea, several different materials and thicknesses of the isolation layer were tested. The pitches of the imaging and therapeutic array were 0.3 mm and 1.2 mm, respectively. Since these pitches were different, several imaging elements were located on one therapeutic element. In this case, isolation layer must stop cross-talk over several elements, the cross-talk was also investigated.

III. RESULTS

Figure 2 showed mode shapes of transducers. When the imaging array was driven, only the driving element vibrated and other imaging elements and therapeutic elements did almost not vibrate. When the therapeutic array was driven, imaging elements located on the driving element vibrated all together. These results showed both the imaging and the therapy mode worked as designed.

Figure 3 showed the impulse responses of the imaging transducer with the isolation layer (a) and without the isolation layer (b). Without the isolation layer, an unwanted response was observed about 2 μsec after the main pulse. The amplitude of the unwanted response is 0.7 times that of the main pulse. The duration between the main pulse and the unwanted response was approximately same as the round-trip propagation time in the therapeutic array. On the other hand, the unwanted response was disappeared with the isolation layer.

Figure 4 showed the cross-talk with adjacent elements. By using the isolation layer, each element in the imaging array could be driven independently. The isolation between two arrays ensured independent oscillatory motions in the imaging array.

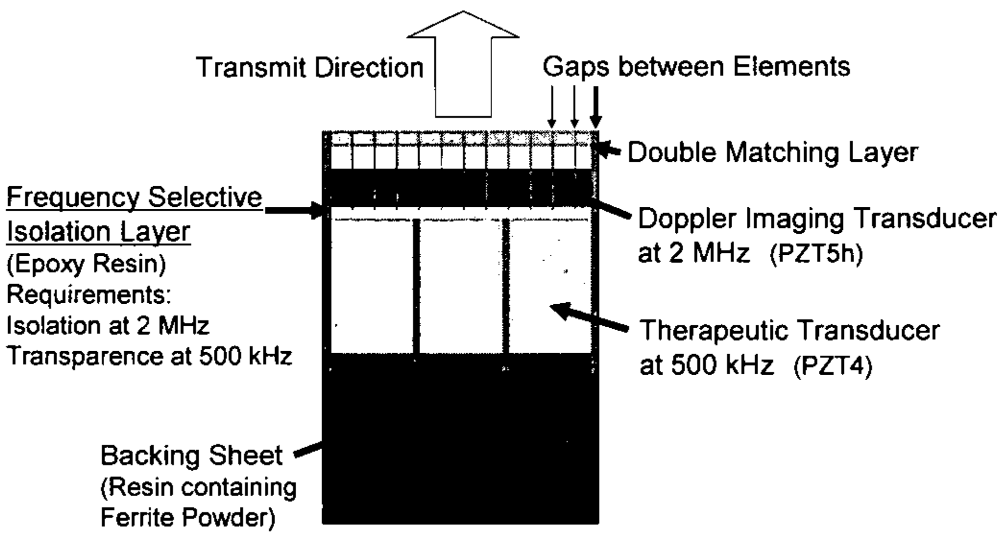

Figure 1: Double-Piezoelectric-Layer Transducer with Frequency Selective Isolation

(a)

(b)

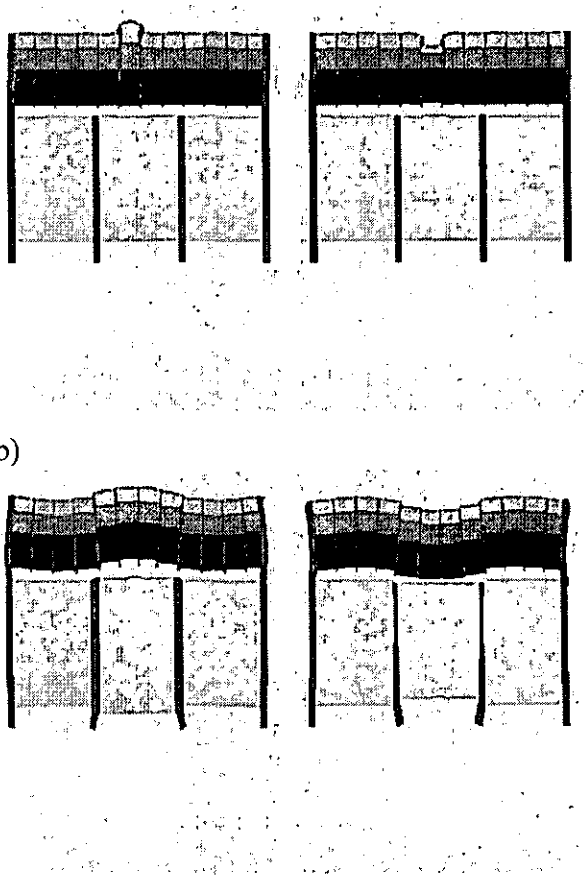

Figure 2: Mode shapes for excitation of Doppler imaging transducer at 2 MHz (a) and Therapeutic Transducer at 500 kHz (b).

IV. Discussion

For several different materials of isolation layers, peak *amplitudes of unwanted temporal response* were shown in Figure 5. Each material of isolation layers were that is used for an acoustic lens, an epoxy resin, a polymer piezoelectric material without poling, a resin containing ferrite powder, a ceramic containing epoxy resin and a PZT ceramic respectively. This graph was normalized by value of the PZT ceramic case. This result showed that unwanted temporal responses depended on acoustic impedance of isolation layers strongly.

(a)

(b)

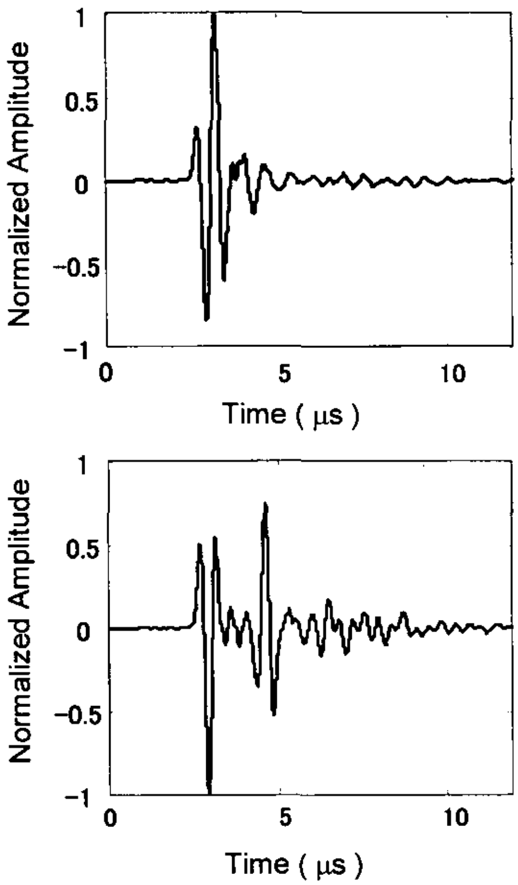

Figure 3: Impulse responses of imaging transducer with isolation layer (a) and without isolation layer (b).

(a)

(b)

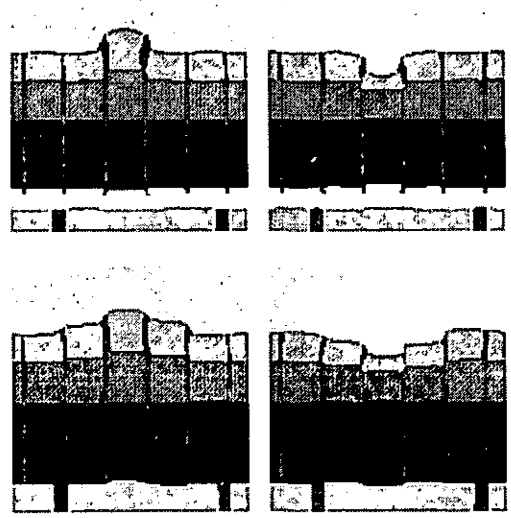

Figure 4: Cross talk with adjacent elements with isolation layer (a) and without isolation layer (b).

In figure 6, we have plotted the acoustic energy of the unwanted temporal responses of the imaging transducer versus the transmission efficiency of the therapeutic transducer, with the thicknesses of isolation layers as the parameter to be changed. The epoxy resin was chosen for the material of isolation layer. The optimum condition was thinner than the matching condition, quarter of the wavelength at 2 MHz.

Since the acoustic impedance of the isolation layer in this simulation was smaller than optimum value indicated at figure 5, the optimum thickness might be thinner than the matching condition.

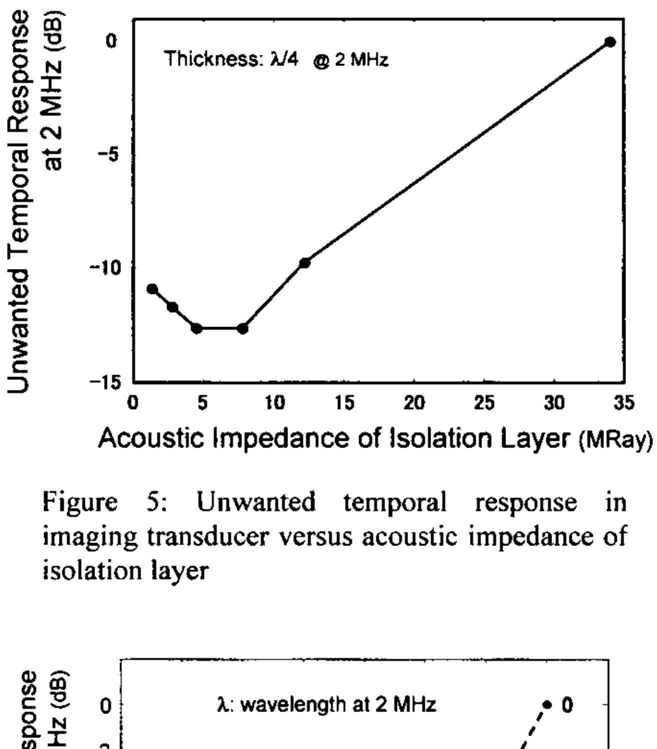

Figure 5: Unwanted temporal response in imaging transducer versus acoustic impedance of isolation layer

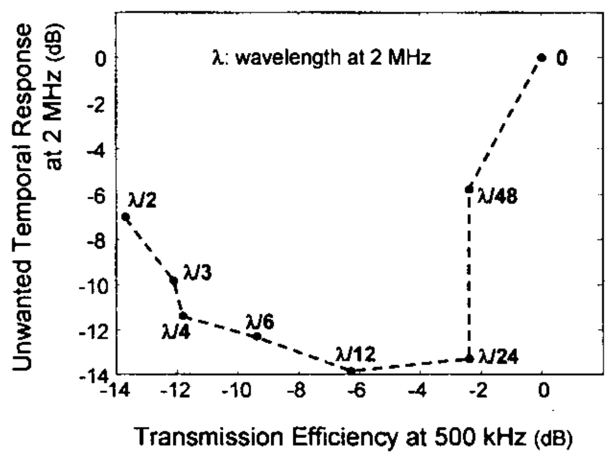

Figure 6: Unwanted temporal response in imaging transducer versus transmission efficiency of therapeutic transducer

V. CONCLUSION

These results showed that the isolation layer with 50 micro-meters reduced the amplitude of the unwanted response at 2 MHz by 13 dB, while it reduced the amplitude of the therapeutic waves at 500 kHz only by 2 dB.

ACKNOWLEDGMENTS

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Analysis of Propagation through Cancellous Bone for Transcranial Ultrasonic Treatment

Takashi Azuma, Shin-ichiro Umemura and Hiroshi Furuhata

Recent advances in biomedical ultrasound are taking transcranial image assisted treatment to its practical stage. In order to achieve accurate transcranial ultrasonic focusing for both imaging and treatment, wave propagation through skull bones has been studied to correct the phase and amplitude aberration induced by them. Pernot et al. performed finite differences simulation based on CT data [1]. They assumed a mixture law of the sound speed in the cancellous bone although the pore size is in a similar order of magnitude with the wavelength. Bosy et al. reported a numerical analysis taking each pore into account [2]. In this study, we first performed finite difference time domain (FDTD) simulation of sound propagation [3] through a dipole, a cancellous layer in a skull bone, in a wide range of the volume ratio of pores in a ultrasonic frequency range of 2-3 MHz. The obtained sound speed was then fit to a mixture law of the α-th power of compliance. The phase can thereby be corrected based on the volume ratio of pores and the thickness of the bone layers, which can be obtained from CT data, without performing time-consuming FDTD simulation through a cancellous bone in prior to each transcranial image assisted treatment.

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