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# Quantitative investigations on thermal response of adipose tissue to focused ultrasonic energy

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## 1. Introduction

HIFU (high intensity focused ultrasound) is one of non-invasive treatments to remove subcutaneous fat tissue for body sculpting. The focused ultrasonic energy can reduce the amount of lipid effectively with minimal nervous damage[1)]. The intercellular space created by HIFU treatment can also promote new collagen regeneration eventually forming tight skin[2)]. A number of investigations have been performed primarily for effective generation of HIFU in light of acoustic intensity and size of focal point[3)]. However, quantitative analysis of adipose tissue response after HIFU treatment is poorly understood. In particular, therapeutic parameters such as applied energy, treatment pitch (i.e., distance between adjacent acoustic beams), and coagulation depth still need to be assessed to obtain the optimal acoustic treatments on lipid reduction with minimal injury to the peripheral tissue. Thus, the aim of the current study was to quantitatively evaluate the effect of HIFU parameters on adipose tissue treatment in terms of temperature elevations and irreversible tissue denaturation.

## 2. Materials and Methods

Thermally reacting polyacrylamide (PAA) was utilized as a tissue phantom to indicate treatment regions during/after HIFU application. PAA was initially mixed with egg-white (10% of solution volume) in order to visualize the extent of thermal denaturation at various energy levels and treatment pitches. In addition, the phantoms were created to consistently have mechanical property of human adipose tissue to reflect clinical conditions. Porcine fat tissue was procured from a local slaughter house and used to verify thermos-mechanical responses of the phantoms as well as to emulate HIFU-assisted lipolysis. As an acoustic source, a 4 *MHz* HIFU transducer (Bluecore Company, Busan, Korea) was employed to induce thermal response of the phantoms and the porcine tissues at various energy levels (0.1 ~ 2 *J*) and treatment pitches (1.5, 1.8, and 2.0 *mm*). Two different focal lengths (3 and 4.5 *mm*) were compared to identify the dependence of treatment efficacy on HIFU beam depth. The total treatment length was 30 *mm*, and each pitch determined the number of acoustic beams for treatment (e.g., 30 *mm* treatment length / 1.5 *mm* pitch = 20 acoustic beams). Thus, the higher pitches resulted in the less number of acoustic beams and the wider distance between two adjacent acoustic beams. During HIFU application, a K-type thermocouple (OMB-DAQ-55, OMEGA, Seoul, Korea) was utilized to real-time monitor temperature elevations at the single beam spot in the sample as a function of acoustic energy and treatment pitch. After the acoustic treatments, all the samples were cross-sectioned and photographed for quantitative evaluations. The degree of structural deformation or irreversible denaturation was estimated by using Image J (National Institute of the Health, Bethesda, MD, USA) and quantified as a function of the applied energy and the treatment pitch. Post-experimentally, the treated porcine tissue was fixed with formalin for four days and stained with hematoxylin and eosin (H&E) for histological assessments. A Mann-Whitney U test as a non-parametric method using SPSS was performed for statistical analysis, and $p < 0.05$ means insignificance.

## 3. Results

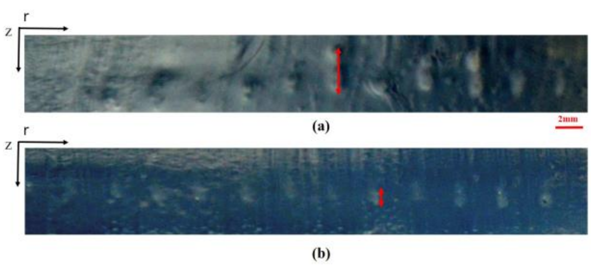


**Fig. 1** Coagulation regions in PAA phantom with focal length of (a) 3 *mm* and (b) 4.5 *mm* under acoustic treatment at 2 *J* (pitch = 1.5 *mm*)

PAA phantoms vividly created a series of whitish dots inside the phantoms (3.0 and 4.5 *mm* below surface) after HIFU application at 2 *J* and treatment pitch of 1.5 *mm*, confirming the applied focal points from an acoustic source (Fig. 1). The observed discoloration resulted from irreversible denaturation of the added egg-white in the phantom. Regardless of focal length, the HIFU transducer created elliptical shape of the denatured regions possibly due to the inherent spatial characteristics of the acoustic beams in the depth direction. Due to the applied pitch, both the focal lengths created the repetitive coagulation zones at every 1.5 *mm*. In spite of the equivalent treatment conditions, the shorter focal length (3 *mm*) induced longer coagulation areas (in depth direction) than the longer focal length (4.5 *mm*) did as shown in Fig. 1. Fig. 2 demonstrates a quantitative comparison of length of major axis in the elliptical coagulation zone between the two focal points. The 3-*mm* focal point showed approximately 35% longer axis that the 4.5-*mm* one (i.e., 1.0 ± 0.5 *mm* for 3 *mm* vs. 0.8 ± 0.1 *mm* for 4.5 *mm*; $p$ = 0.008), implicating that the shorter focal length could cover a wider range of adipose tissue during HIFU treatments, given the same conditions.

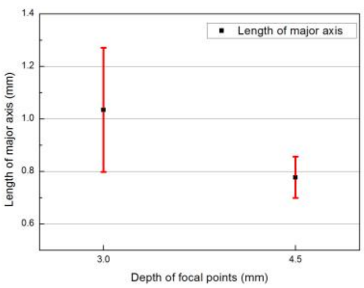


**Fig. 2** Comparison of major axis in coagulation area at different focal points ($N$ = 10)

Figure 3 demonstrates temporal development of temperature during 2-*J* HIFU application on adipose tissue (3-*mm* focal depth) as a function of treatment pitch. Regardless of treatment pitch, the temperature reached the maximum value at around 4 *s* after the HIFU application and decreased exponentially. The measured peak average temperatures were 31.8, 29.2, and 28.6 ℃ at 1.5, 1.8, and 2.0 mm. Thus, the smallest pitch (i.e., 1.5 *mm*) induced the highest temperature (up to 31.8 ℃) along with more rapid increase rate (15.9 ℃/*s*), in comparison with the other conditions. The degree of the temperature elevation linearly increased with the applied acoustic energy. The higher temperature at the smaller pitch could be associated with the closer distance between the two consecutive focal points, eventually leading to thermal accumulation. Additionally, a few sudden temperature rises were noticed (Fig. 3(a)) possibly owing to thermal response from adjacent beam spots. Figure 3(b) compares the degree of temperature elevation at various treatment pitches. The shortest pitch resulted in 10% and 13% higher temperature increase than 1.8 and 2.0 *mm* did (i.e., 8.7 ± 1.7 ℃ for 1.5 *mm* vs. 6.3 ± 1.2 ℃ for 1.8 *mm* and 5.6 ± 1.8 ℃ for 2.0 *mm*; $p$ = 0.01). Histology analysis confirmed that the HIFU-treated regions underwent irreversible denaturation due to temperature reaching the melting point of the adipose tissue (30 ~ 32 ℃).

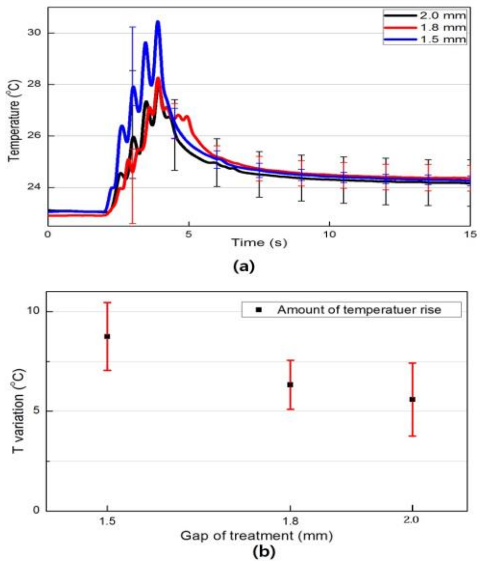


**Fig. 3** Thermal response during HIFU application at various pitches: (a) temporal temperature development and (b) temperature variations ($N$ = 5)

## 4. Conclusion

The current study investigated physical effects of acoustic parameters on HIFU-assisted lipolysis. Both acoustic energy and short treatment pitch determined the degree of tissue coagulation. Further investigations will examine *in vivo* healing response after treatment in terms of collagen remodeling.


### Acknowledgment

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### References


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