

A study on the factors affecting the temperature distribution within intervertebral disc during electrothermal therapy

G. R. Tack*

Dept. of Biomedical Eng.
Konkuk Univ.
Chungju, Chungbuk, Korea

B. S. Lee

Dept. of Biomedical Eng.
Konkuk Univ.
Chungju, Chungbuk, Korea

S. C. Chung

Dept. of Biomedical Eng.
Konkuk Univ.
Chungju, Chungbuk, Korea

J. S. Choi

Dept. of Biomedical Eng.
Konkuk Univ.
Chungju, Chungbuk, Korea

B. Y. Lee

Division of Anatomy
Konkuk Univ.
Chungju, Chungbuk, Korea

J. H. Yi

Dept. of Biomedical Eng.
Konkuk Univ.
Chungju, Chungbuk, Korea

Abstract - *Intradiscal electrothermal therapy, a new and minimally invasive technique for the treatment of discogenic low back pain, is introduced recently. This procedure involves the percutaneous threading of a flexible catheter into the disc under fluoroscopic guidance. The catheter, composed of thermal resistive coil, heats the posterior annulus of the disc, causing contraction of collagen fibers and destruction of afferent nociceptors. This study tries to investigate the effects of the important factors of this procedure such as heat source temperature and heat loading time on the temperature distribution within the intervertebral disc. This study utilized both finite element analysis and the experiment. The results showed that when the heat source temperature was kept up 80 °C for 1,020 seconds, the temperature of inner annulus reached at 45 °C up to the distance of 15.6mm from heat source, which explains the coagulation of inner annulus. When the same heat source was used, the temperature of inner nucleus reached at 60 °C up to the distance of 9mm from heat source, which explains the contraction of inner nucleus.*

Keywords: Intervertebral disc, discogenic pain, electrothermal therapy, finite element analysis

1 Introduction

There are lots of factors affecting low back pain. However it is not easy to find the direct causes of patients'

back pain. Since for most patients it is difficult to distinguish the exact cause of the pain from several factors, generally treatment of the pain depends on the conditions of the patient. The clinical evidences show that the fact that the cause of low back pain is in disc itself is increasing [1]. Among patients with chronic low back pain, the patient with discogenic pain itself is estimated about 40% [2]. Invasive surgical procedures such as lumbar discectomy have been performed as a treatment according to the studies done so far. It is reported that for more than 80% of the patients who had discectomy the pain is reduced significantly at first [3]. However as time passes, there is a possibility to cause significant problems, and only about 29% ~ 37% of patients are satisfied with the results, and about 38% of the patients have to do a surgical operation again [3, 4]. As an alternative for these kinds of invasive surgical approach, a simple, minimally invasive, and economical procedure is required. Recently intradiscal electrothermal therapy is introduced [5-9], which is a new, economical and minimally invasive technique for the treatment of discogenic low back pain. This procedure involves the percutaneous threading of a flexible catheter into the disc under fluoroscopic guidance. The catheter, composed of thermal resistive coil, heats the posterior annulus of the disc, causing contraction of collagen fibers (pain relieving mechanism I) and destruction of afferent nociceptors (pain relieving mechanism II). The temperatures for these mechanisms are known to be higher than 60 °C and 45 °C, respectively [7]. Pain relieving mechanisms of the intradiscal electrothermal therapy procedure which directly heats the disc itself are as follows:

pain is relieved by the destruction of afferent nociceptors which sense the pain by causing thermal coagulation with more than 45°C heat applying at the annulus of the disc. Pain is relieved by the contraction of type I collagen fibers in annulus by applying more than 60°C heat.

Based on these mechanisms, this study tried to investigate the important factors such as heat source temperature and heat loading time affecting the temperature distribution within intervertebral disc during electrothermal therapy. By checking the temperature distribution within intervertebral disc, this study tried to confirm the actual temperature distribution for pain relieving mechanisms. This study utilized both computer simulation using the finite element analysis and the biomechanical experiment for the verification of the results of the FE analysis. Through these procedures, it is believed that optimal heat source temperature and heat loading time be suggested for optimal clinical results.

2 Method

Experiment consists of two parts. One is to measure the temperature distribution within intervertebral disc of the swine during electrothermal experiment. The other is to find the density and specific heat of the annulus and nucleus of intervertebral disc for material properties of the FE analysis. Heat conductivity for the FE analysis is calculated by heat diffusivity based on the measured temperature distribution within intervertebral disc. Functional spinal units of 5 month old swine were prepared for the experiment. The experimental setup for this study consists of the manufactured saline chamber, stereo-tactic positioning jig, and 10-channel thermometer (MV200). To heat both the annulus and the nucleus, heat source was positioned in the boundary between the annulus and the nucleus by incising the middle of intervertebral disc about 7mm. To measure the temperature during electrothermal experiment, eight thermocouples were placed at the annulus and the nucleus with 2 ~ 3mm distance apart. The prepared specimen was fixed with jig and placed at the saline chamber. To minimize the temperature distortion due to the inflow of saline solution into the incised gap, the incised gap of the specimen was covered with agar. The saline chamber which consisted of the prepared specimen, heat source, and thermocouples was filled with 0.9% saline solution and temperature was maintained with $37 \pm 2^\circ\text{C}$. Poly-switch was used as heat source, actual heat source temperature was set to 80°C, and heat loading time was set to 17 minutes. After finishing experiment, X-ray images were taken to get the structural (geometry) information of intervertebral disc and the location of heat source and thermocouples for the FE analysis as shown in Fig. 1 and the density and specific heat of the annulus and nucleus was measured.

Numerical analysis was carried out using the FE analysis. The measured material properties and geometric information was used for the analysis (Table 1). As shown in Fig. 2, this study used 10,980 numbers of brick element and 12,551 numbers of node. Initial temperature of intervertebral disc was set to 37°C, and outside temperature was set to 37°C as a boundary condition. The boundary value of the upper and lower vertebrae which connected with intervertebral disc was not constrained. Experimentally measured heat source temperature was used as heat source and loading time was set to 17 minutes which was believed as a clinically effective heat loading time. FE analysis was carried out with ANSYS v7.0 (ANSYS Inc, USA).

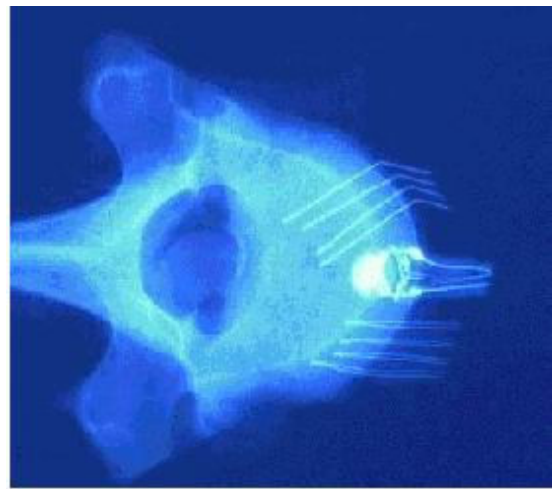


Fig. 1 Fluoroscopic image of intervertebral disc with thermocouples and heat source

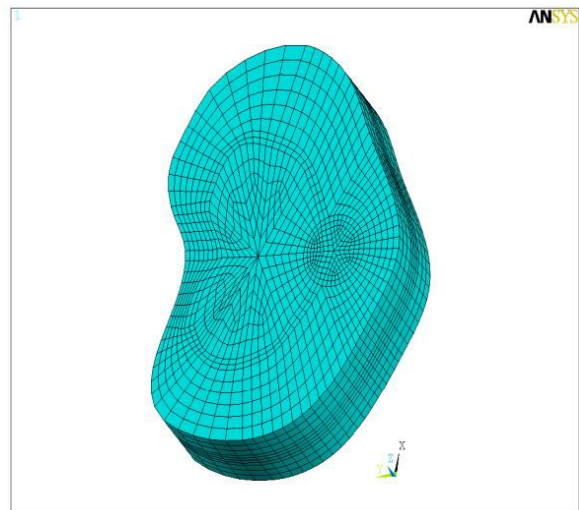


Fig. 2 A typical example of finite element model

Table 1. Geometry and material properties of intervertebral disc (Human & Swine)

Property	Nucleus (Human)	Annulus (Human)	Nucleus (Swine)	Annulus (Swine)
Major Diameter (mm)	35	60	measured data	measured data
Minor Diameter (mm)	25	45		
Height (mm)	13	13		
Specific Heat (Nmm/kg/°C)	3e6	3e6	3e6	3e6
Density(kg/mm ³)	1.09e-6	1.12e-6	1.082e-6	1.128e-6
Conductivity(N/sec/°C)	1.472	1.008	0.8719	0.67202

3 Results

FE analysis showed that the temperature for thermal coagulation at the annulus ($\geq 45^\circ\text{C}$) was distributed up to 15.6mm from heat source and the temperature for contraction of the nucleus ($\geq 60^\circ\text{C}$) was up to 9mm from heat source (Fig. 3). It is known that for clinical effectiveness it is necessary to keep 70°C for 90 sec [7, 8]. Houpt [7] tried to keep their specimens 70°C for 90 sec, but they could not get the enough temperature to destruct afferent nociceptors. After keeping their temperature 70°C for 800 sec, they reported that the region for proper pain relieving mechanism ($\geq 45^\circ\text{C}$) was reached up to 11mm from heat source. This study used 80°C for 1020 sec with swine specimen. It can be concluded that our results are similar to Houpt's results if it is considered that the material properties of human and swine, heat loading time, and heat temperature are different. Fig. 4 shows the temperature distribution at nucleus region (8mm), annulus region (8.5mm), and nucleus region (12.5mm) from heat source, respectively, and red color with error bar indicates the results of the FE analysis and black color indicates the measured data. At nucleus region (8mm) from heat source, temperature distribution of experiment is very similar to that of simulation (Fig. 4(a)). At annulus region (8.5mm), nucleus region (12.5mm), and other regions from heat source, there was a minimum difference of 0.2°C and a maximum difference of 5°C between experiment and simulation, which showed similar results (Table 2).

4 Conclusion

Through this study, it was able to analyze the temperature range of inner intervertebral disc by two mechanisms which are known to alleviate pain clinically. The results showed that when the heat source temperature

was kept up 80°C for 1,020 seconds, the temperature of inner annulus reached at 45°C up to the distance of 15.6mm from heat source, which explains the pain relieving mechanism I, i.e., coagulation of inner annulus by heat. When the same heat source was used, the temperature of inner nucleus reached at 60°C up to the distance of 9mm from heat source, which explains the pain relieving mechanism II, i.e., contraction of inner nucleus by heat. To make progress on this study, it is necessary to get accurate material properties of human intervertebral disc and geometric information from CT or MRI. Through these procedures, it is believed that optimal heat source temperature and heat loading time be suggested for optimal clinical results.

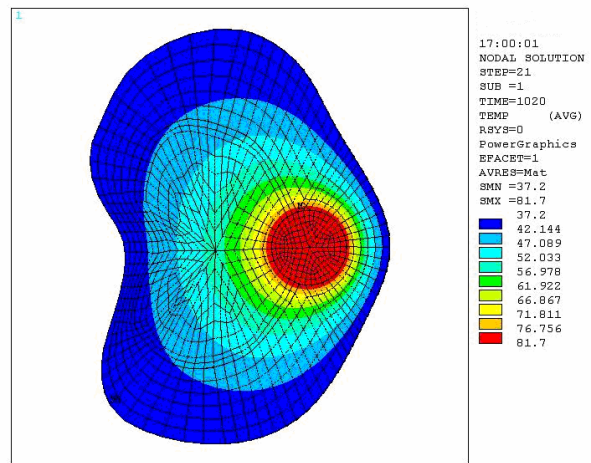


Fig. 3 A typical result of finite element analysis

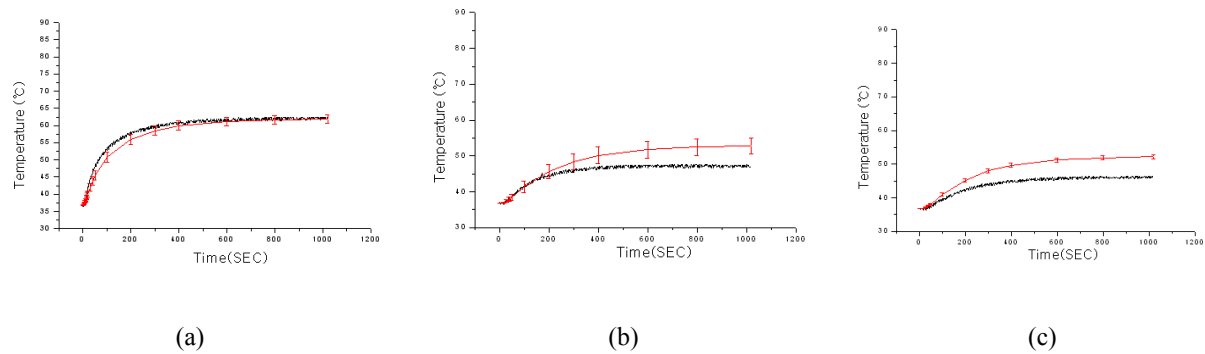


Fig. 4 Temperature distribution measured using 10-channel thermometer (a) at nucleus region (8mm) from heat source, (b) at annulus region (8.5mm) from heat source, (c) at nucleus region (12.5mm) from heat source

Table 2. Temperature distribution at measured points

Distance from heat source (mm)	Annulus				Nucleus			
	7	8.5	12	14	8	10	12.5	16
Temperature distribution by experiment (°C)	54.5	47.1	43.7	41.1	62	55.1	46.4	43.3
Temperature distribution by finite element model (°C)	58.2	52.7	47.9	44.0	61.8	57.8	52.1	47.9

5 Acknowledgement

This work was supported by grant No. (R01-2006-000-11131-0) from the Basic Research Program of the Korea Science & Engineering Foundation.

6 References

- [1] J. Malinsky, "The ontogenetic development of nerve terminations in the intervertebral discs in man," *Acta Anat*, Vol. 38, pp. 96-101, 1959.
- [2] A. Schwarzer, C. Aprill, R. Derby et al. "The relative contributions of the disc and zygapophyseal joint in chronic low back pain," *Spine*, Vol. 19, 801-806, 1994.
- [3] C.K. Lee, P. Vessa, J.K. Lee, "Chronic disabling low back pain syndrome caused by internal disc derangements: The results of disc excision and posterior lumbar interbody fusion," *Spine* Vol. 20, 356-361, 1995.
- [4] M.A. Linson, H. Williams, "Anterior and combined antero-posterior fusion for lumbar disc pain: A preliminary study," *Spine* Vol. 16, 143-145, 1991.
- [5] J.A. Saal, J.S. Saal, "Intradiscal electrothermal therapy for the treatment of chronic discogenic low back pain," *Operative Techniques in Orthopedics*, Vol. 10, 271-281, 2000.
- [6] J.A. Saal, J.S. Saal, "Intradiscal electrothermal treatment for chronic discogenic low back pain: prospective outcome study with a minimum 2-year follow-up," *Spine*, Vol. 27, 966-973; discussion 973-974, 2002.
- [7] J.C. Houpt, E.S. Conner, E.W. McFarland, "Experimental study of temperature distributions and thermal transport during radiofrequency current therapy of the intervertebral disc," *Spine*, Vol. 21, 1808-1813, 1996.
- [8] M.G. Fehlings, "Point of View: Experimental study of temperature distributions and thermal transport during radiofrequency current therapy of the intervertebral disc," *Spine*, Vol. 21, 1812-1813, 1996.
- [9] J.A. Saal, J.S. Saal, "Intradiscal electrothermal therapy for the treatment of chronic discogenic low back pain," *Clin Sports Med*. Vol. 21(1), 167-87. Review, 2002.