Biomed Eng Lett (2012) 2:173-178
DOI 10.1007/s13534-012-0069-4

ORIGINAL ARTICLE

Needle Insertion Force Exerted on Various Breast Tissues: Experimental Study and Finite Element Analysis

Han Yong Chun, Hyun Chul Jung, Min Tae Kim, Kwang Gi Kim and Kyoung Lan Ko

Received: 7 September 2012 / Accepted: 20 September 2012
© The Korean Society of Medical & Biological Engineering and Springer 2012

Abstract

Purpose In this study, we measured the needle insertion force exerted on various breast tissues including those of a breast phantom, cattle tissue, and human tissue, according to needle insertion speed, and compared it using finite element analysis.

Methods As target breast tissues in our experiment a breast phantom for the medical experiment, breast tissue of slaughtered cattle, and surgically removed parts of breast cancer patients were used. A biopsy robot designed and manufactured by the biomedical engineering branch of the National Cancer Center in Korea was used for the measurement of needle insertion force.

Results The experimental result proved that the needle insertion force decreased as needle insertion speed was increased regardless of the type of breast tissue used in our study. And the result of the finite element analysis showed that the stress increased as the depth increased.

Conclusions Finite element analysis performed using commercial software ANSYS Workbench showed similar results to the experiment and proved that this technique can be applied not only to the breast but also to various fields of medical study.

Keywords Mammography, Needle localization, Breast tissue, Needle insertion force, Finite element analysis

Han Yong Chun, Hyun Chul Jung, Min Tae Kim, Kwang Gi Kim (✉)
Biomedical Engineering Branch, National Cancer Center, Gyeonggi-do, 410-769, Korea
Tel : +82-31-920-2241 / Fax : +82-31-920-2242
E-mail : kimkg@ncc.re.kr

Kyoung Lan Ko (✉)
Center for Breast Cancer, National Cancer Center, Gyeonggi-do, 410-769, Korea
Tel : +82-31-920-1186 / Fax : +82-31-920-1171
E-mail : kokr@ncc.re.kr

INTRODUCTION

According to the cancer statistics of the United States in 2010, there were a total of 207,090 breast cancer patients among a total of 739,940 female cancer patients, accounting for approximately 28% of the total breast cancer population, making it the largest percentage of female cancer patients in the entire United States [1]. It has also been reported that the number of breast cancer patients have been increasing every year since 1975 up until 2005 [1]. Furthermore, according to the cancer statistics of the Ministry of Health and Welfare in Korea, during 2008, there were 12,584 breast cancer patients among a total of 85,799 female cancer patients making up 14.7 % of the total female cancer population in South Korea [2]. This is the second largest percentage among female cancer patients [2]. Nevertheless, the survival rate of breast cancer patients has increased [1, 2], due to advances in medical techniques such as early detection and surgical techniques throughout the world [3, 4].

Currently, the diagnosis of breast cancer is made through palpation, ultrasonography, and mammography [5]. For surgery of microcalcifications detectable only on mammography, mammography-guided needle localization is typically performed for which exact positioning is a prerequisite [6]. As shown in Fig. 1, mammography-guided needle localization is performed for tumor localization in the breast, using mammography, and a long thin needle which is inserted into the tumor. However, inserting the needle correctly is often difficult due to the needle bending phenomenon during needle insertion. This is especially true in a population with dense breast tissue which becomes even more hardened when compressed, as in Korean women who often have dense breast tissue [7]. Thus, measurement of needle insertion force on breast tissue was initiated for the development of a device which can more efficiently insert the needle in these and other women.

In previous studies, the mechanical analysis of breast

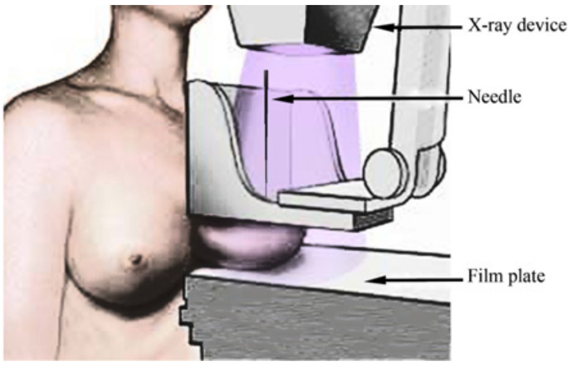

Fig. 1. Example of mammography-guided needle localization.

tissue [8-10], and needle insertions, as well as simulation studies have been performed for breast and liver tissue [11, 12]. However, to our knowledge, there has been no research on the measurement of needle insertion force against human breast tissue. In this paper, we measured and analyzed the needle insertion force on a breast phantom, breast tissue of slaughtered cattle, and human breast tissue according to needle insertion speed, and compared these results using finite element analysis.

MATERIALS AND METHODS

Measurement of needle insertion force

For the purposes of our experiment, needle insertion was performed in a variety of breast tissue. Fig. 2 shows the various types of breast tissue used in this experiment. Among them, as shown in Fig. 2a, a Triple Modality Biopsy Training Phantom (Model 051, CIRS, Norfolk, Virginia, USA) was used. This breast phantom accurately reflects the characteristics of physical density and attenuation of human breast tissue, and has been often used in various experiments such as mammography, magnetic resonance imaging (MRI), and ultrasonography, as it also has resistance to needle insertion similar to human breast tissue. However, this breast phantom was modeled on the basis of Western women, whom have slightly different breast densities than those of Korean women whose breast tissue are typically more dense [7]. In addition, as shown in Fig. 2b, the breast tissue of cattle was also used in the experiment. The cattle was slaughtered 3 days prior to the experiment. The breast tissue was stiff through rigor mortis, but needle insertion was still possible. Finally, as shown in Fig. 2c, human breast tissue was also obtained immediately after surgery from a breast cancer patient. Although needle localization is typically performed on the patient prior to surgical removal, as this experiment required multiple needle insertions according to needle insertion speed, we determined to use resected breast tissue due to safety concerns. A biopsy robot designed and

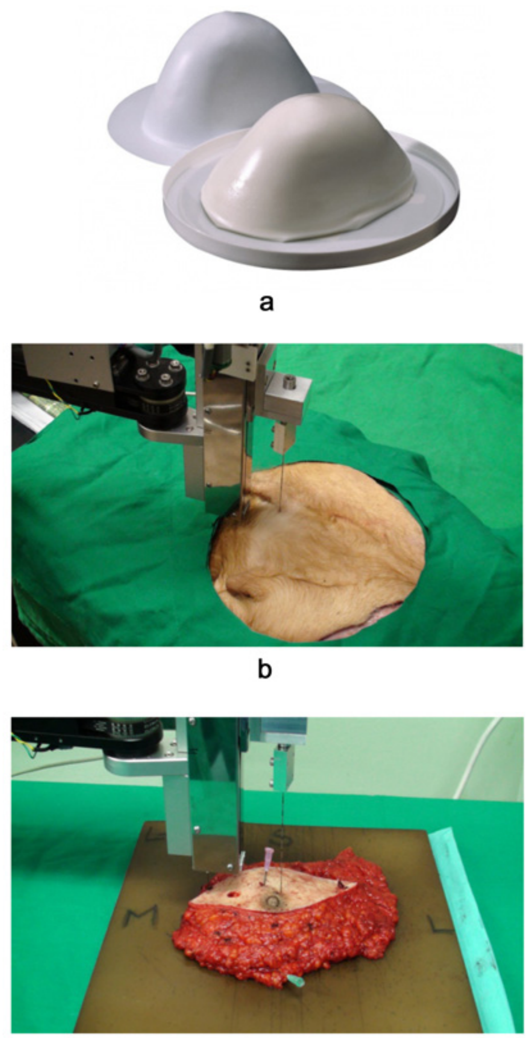

Fig. 2. Breast tissue used in the experiment; (a) breast phantom, (b) cattle breast tissue, (c) human breast tissue.

manufactured by the biomedical engineering branch of the National Cancer Center in Korea was used for needle insertion to measure the needle insertion force [13]. This device was attached to a biopsy needle or ultrasound probes at the end effector, and motors and encoders were used to control the speed and position of the end effector. In addition, a loadcell (CDFS-10, Bongshin, Seoul, Korea) was installed to measure tensile and compressive force during needle insertion and removal. The experiment was performed so that the needle insertion speeds were set at 4, 6, 8 mm/s, with needle insertion depths set at 50 mm for the breast phantom and the breast tissue of cattle, and 30 mm for the human breast tissue depending on the thickness of the breast tissue.

Finite element analysis

The breast phantom and the human breast tissue were