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Development of a New Compression Paddle for Enhanced Image Acquisition During Mammography

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ABSTRACT

In this study, the shape and function of a mammography compression paddle was revised and investigated with regard to contrast and image quality in patients with pectus carinatum.

The center of the novel compression paddle surface had a radius of curvature of the contact area with the chest wall. The double structure of the compression paddle frame provided sufficient contact with the chest wall and reduced pain.. Springs in the back allowed an open space of 30 mm. we compared the increasing rate of total area and posterior nipple line (PNL) and the image surface plot.

With the newly developed compression paddle, the averaged increasing rate of the total area in 10 patients with pectus carinatum was 9.65% and 6.96% in the craniocaudal (CC) and mediolateral-oblique (MLO) directions, respectively; the averaged increasing rate of the PNL was 9.18% and 4.55% in the CC and MLO directions, respectively; and the averaged increasing rate of the breast length side chest wall was 3.97% in the CC direction. The newly developed compression paddle appeared to contain more breast tissue without degradation in image contrast and quality.

The novel breast compression paddle was streamlined, thereby reducing friction with the chest wall. It also contained substantial breast tissue because the springs make it possible to move back and forth to match breast chest size.

The developed compression paddle will provide a wider diagnostic range for mammography.

Keywords: *Mammography, Device, Compression paddle, Carinatum, Caraniocaudal (CC), Mediolateraloblique (MLO)*

Mathematics Subject Classification: *51M25, 92C50*

Journal of Economic Literature (JEL) Classification: *I119*

Introduction

It is important to treat breast cancer at an early stage before symptoms appear; therefore, the importance of mammography is rising. In the past, mammography was conducted only for the diagnosis and management of patients with symptoms. However, it is important to monitor changes over time because breast diseases are more likely to develop into cancer. For this reason, clinicians need to conduct screening tests universally and systematically for women with and without symptoms[1,2].

Mammography is divided, based on its purpose, as a screening test or a diagnostic test. A screening test is a basic test conducted in the craniocaudal (CC) and mediolateral-oblique (MLO) directions[3].

Pressure on the breasts in mammography improves resolution by holding the image receptor and breasts

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closely together, and increases the quality of the image by reducing the thickness of the breasts. Additionally, it can make the image clear by separating the image from folded breast tissues, enhancing the contrast, and reducing the exposure dose[4,5].

However, the end of the image recipient and the compression paddle has straight lines. As a consequence, patients with pectus carinatum complain of pain because of friction from the compression paddle, and the image fails to include the inside and outside of the breast tissue.

Pectus carinatum is characterised by excessive protrusion of the chest wall. Hippocrates called the condition "pointed chest," and its frequency is 0.06%[6]. However, this statistic was derived only from women who have been diagnosed with pectus carinatum. More women are expected to have pectus carinatum as it becomes frequently seen in mammography.

Breast cancer tests are conducted using sonography, magnetic resonance imaging, and computed tomography (CT). Magnetic resonance imaging has the highest sensitivity for women in their 30s, but its high cost and false-positive results prevent it from being applied to the average woman. For conditions that breast cancer testing is recommended at least once a year, CT is inappropriate as a screening test because of the large radiation exposure dose. However, sonography is inexpensive and does not have a large exposure dose; but its detectability of calcification, which is a marker of malignant breast cancer, is lower than that of mammography, which uses radiation. For a breast cancer test, it is therefore most appropriate to recommend mammography using general X-ray imaging as the screening test. The development of a new compression paddle is needed to expand the value and diagnostic area of the image.

In this study, compression paddles were developed that can be applied to women with pectus carinatum and normal people. The end of the compression paddle is round, somewhat like the chest, to depict the breast tissues as much as possible, and the frame of the compression paddle is devised to move back and forth to fit the form of an individual's chest. This study aimed to develop compression paddles with high diagnostic utility by obtaining images through applying conventional compression paddles and the newly developed compression paddles to patients with pectus carinatum form of normal. This study also aimed to evaluate the newly developed compression paddles, after comparing the increasing rate of the total area and posterior nipple line (PNL) and image surface plots of the newly developed compression paddle with those of the conventional paddle in mammography.

Materials and Method

Materials

Mammography: Images of the breasts of women with pectus carinatum were obtained using the newly developed compression paddle. A digital X-ray mammography unit (Alpha ST; GE Healthcare, Milwaukee, Wisconsin, USA) was the equipment used. The target/filter combination of the equipment was Mo/Mo, and the computed radiography type of field of view was 18×24 cm.

Utility Evaluation: After obtaining images using the currently used compression paddles and the newly designed compression paddles through a Digital Imaging and Communications in Medicine (DICOM) file, the images were evaluated using Image J (version. 1.49h, Wayne Rasband, National Institutes of Health, USA), a digital image analysis program provided by the United States National Institutes of Health (NIH, Bethesda, MD, USA). With the Image J program, the utility of the obtained images were evaluated by measuring the whole area of the breasts and the length of the breast on the chest side and the PNL.

Method

Study Participants: The target of the study was female patients with pectus carinatum who were requesting mammography. They were recruited from five hospitals in Seoul, Korea from August 20, 2014 to September 30, 2014. The patients were in their 30s to 40s and weighed more than 50 kg. The study received approval from our Institutional Review Board. A test with the conventional compression paddle was conducted first. After obtaining the patients' written agreement to participate in the study, two images were tested, which included one image in the craniocaudal direction and the second image in the mediolateral direction, using the newly developed compression paddle.

To acquire images of female patients with pectus carinatum who visited the hospital, we conducted a test using the same amount of pressure for the craniocaudal direction and mediolateral direction. We acquired the images through a DICOM file and Joint Photographic

Experts Group (JPEG) file. We measured, compared, and evaluated the size of the whole breast area, the surface plot, and the length of the PNL using Image J software (NIH).

Statistical Analysis: To evaluate significance, based on the effective area of the pressed area through the compression paddle, SPSS statistical software (ver. 22; SPSS, Chicago, IL, USA) was used. The Wilcoxon signed-rank test, a nonparametric test, was conducted as a paired t-test to analyse the pressure effective area obtained by the developed compression paddle. P value less than 0.05 was considered to be statistical significance.

Results

Development of the new compression paddle for mammography

The plan and design of the new compression paddle for mammography: The conventional breast compression paddle is rectangular with flat sides that press the breasts in parallel with the grid sides of the chest. However, the actual model of the human body is a bit convex, which makes the inner and outer parts of the breasts out of the sight of the pressed area on an image when pressing. Therefore, we curved the part that touches the chest side of the compression paddle and applied a spring to make it move back and forth automatically by giving mobility through the protrusion side of the chest wall.

As show figure 1, to determine the size of the curve, CT images of 10 people—five people with a slim body type and five people with a large body type—were used for measurements. The size of the protrusion depends on the size of the ribcage. Two CT specialist radiological technologists and one radiologist comprised the radiological team. For measurement, the spot from the second rib to the sixth rib, which is the anatomical position of the breast, was the reference point. We drew a vertical line from the centre of the body to the end of the body surface to get the chest height of Rib 2 and Rib 6, respectively. Rib 2 had a thickness of 115–175 mm and Rib 6 had a thickness of 155–215 mm, an average difference of 40 mm. There was a 5 mm margin of error, depending on the body type. The end of the breast compression paddle was accordingly constructed with a 10 mm curvature radius and a 30 mm curvature radius. To correct for differences in the chest walls of between individuals, 40–50 mm of mobility was secured by inserting a spring to allow the breast compression paddle to move back and forth.

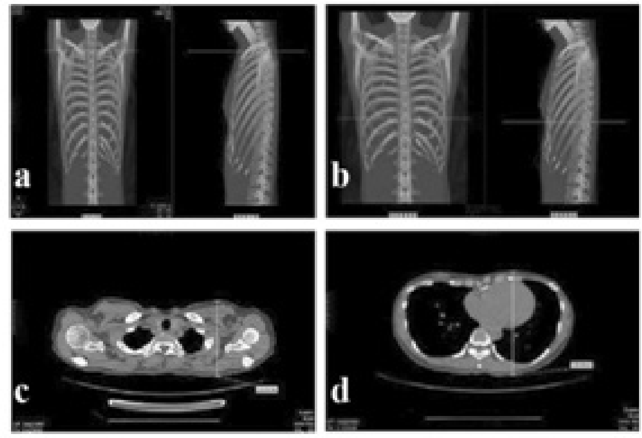

Figure 1: Measurement of the chest length at rib 2 (a and c) and rib 6 (b and d) using computed tomography

Production of the compression paddle for mammography: The length of the receptor of the mammography units was 180×240 mm, and the side size of the breast starting from the nipple of the chest phantom on chest CT was 172.3 mm. Based on this information, 40 mm was spaced out from both ends of the side that touches the chest wall side of the compression paddle, and the length of the radius of curvature was 160 mm. The thickness of the compression paddle was 30 mm, which is like that of the conventional compression paddle and meets the standard of less than 40 mm that the Ministry of Food and Drug Safety (Seoul, Korea) regulates. To prevent the breast tissue from going up on the compression paddle when pressing, it was raised vertically against the surface of the compression paddle with 55 mm of height.

The radius of curvature of the compression paddle surface on the chest wall side of the compression paddle was 10 mm and 30 mm. For the compression paddle with a size of 30 mm, too much of the breast tissue was missing. It therefore had a greater loss of breast tissue, compared to the conventional compression paddle. As a result, the radius of curvature of 30 mm was excluded and 10 mm was used instead. The conventional compression paddle frame has the simple role of supporting and fixing the compression paddle, whereas the developed compression paddle frame adds mobility to the chest side by allowing vertical movement. As show figure 2 and figure 3, this is to supplement the degree to which the compression paddle is pushed out to correct the difference of 40 mm in the chest because of individual differences in the size of the chest. In addition, two compression paddle frames were made and placed inside and outside; the inner frame extended from the outer frame by 30 mm, and the inner frame and outer frame were interlocked to move back and forth through a grove cut between them.

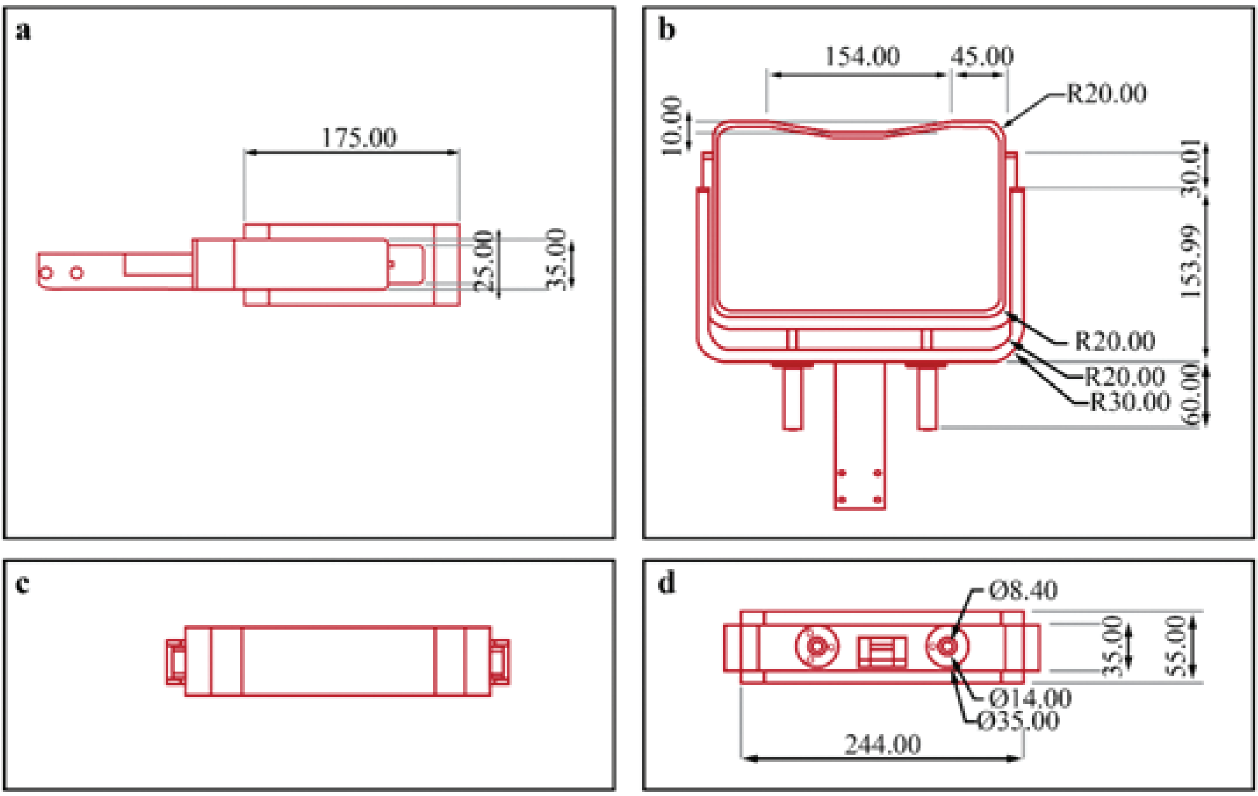

Figure 2: A planar image of the newly developed compression paddle as viewed from the front (a), laterally (b), and from below (c)

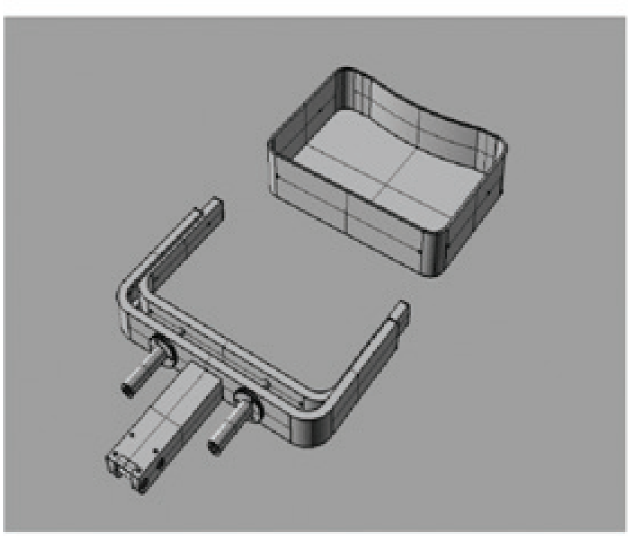

Figure 3: The planar figure of the entire newly developed compression paddle.

Utility evaluation of the new compression paddle for mammography

Utility evaluation of image by Image J: As show table 1, the measured values of the breast area in the images in which the developed compression paddle was applied were all higher than those obtained with the conventional compression paddle. The whole area of all 10 people increased 9.65% on average in the CC image and increased 6.96% on average in the MLO image. The PNL increased 9.18% on average in the CC image and 4.55% in the MLO image. The breast length on the chest wall side increased 3.97% in the CC image.

Table 1: The Increase Rate of the Breast Area in All Patients

Case	Measurement list					
	Item	Area (%)		PNL (%)		Breast length side chest wall (%)
		CC	MLO	CC	MLO	CC
Case 1	Increase rate	12.71	7.17	5.89	1.49	2.57
Case 2	Increase rate	1.07	10.92	6.03	23.65	10.42
Case 3	Increase rate	26.35	6.40	15.94	5.19	11.76
Case 4	Increase rate	4.15	3.30	3.90	0.65	2.98
Case 5	Increase rate	9.56	7.17	5.89	1.49	1.89
Case 6	Increase rate	29.65	9.96	28.50	3.06	4.13
Case 7	Increase rate	0.91	2.32	4.62	0.28	0.75
Case 8	Increase rate	2.46	7.75	4.69	1.96	3.55
Case 9	Increase rate	3.13	6.91	9.03	3.63	0.99
Case 10	Increase rate	6.51	7.66	7.35	4.12	0.67
Average		9.65	6.96	9.18	4.55	3.97

As show figure 4, based on the results of the comparisons of the surface plots, all images of the 10 targets had a similar form of surface outline without the degradation of the image quality and contrast.

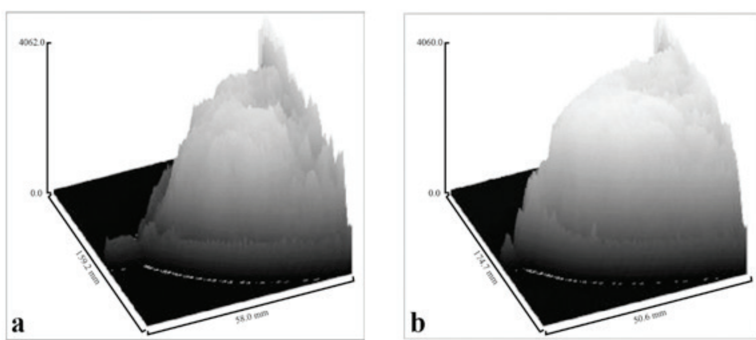

Figure 4: The flatness images. The conventional compression paddle (a) and the newly developed compression paddle (b)

Evaluation of Significance: As show table 2, the Wilcoxon signed-rank test, a nonparametric test, showed a significant difference in all comparisons, and that the measured values of the images in which the newly developed compression paddle was used were higher on average than those of the conventional compression paddle ($p<0.05$).

Table 2: Wilcoxon signed-rank test

Test statistics[a]					
	CC_new_area-CC_ori_area	CC_new_PNL-CC_ori_PNL	CC_new_wall-CC_ori_wall	MLO_new_area-MLO_ori_area	MLO_new_PNL-MLO_ori_PNL
Z	-2.599[b]	-2.803[b]	-2.191[b]	-2.090[b]	-2.701[b]
Asymptotic p-value (both sides)	0.009	0.005	0.028	0.037	0.007
a Wilcoxon signed-rank test.					
b Rankings are based on the negative.					
CC, craniocaudal; MLO, mediolateral-oblique; PNL posterior nipple line.					

Discussion

Breast cancer has had the highest cancer incidence rate for women since 2001, and it is rapidly increasing because of the decreased birth rate and increased avoidance of breast feeding[7]. Mammography is a very important diagnostic method for the early diagnosis of breast cancer and has strong clinical utility as a screening test for micro calcification of breast lesions[8]. However, patients tend to avoid mammography because of the pain incurred on account of pressure applied during the test. Pressure is necessary in mammography to reduce the exposure dose and improve image quality[9].

Measurements of adult women between 20 and 59 years old indicate that women in their 40s and 50s have a greater tendency of having droopiness and obesity horizontally in their breasts, compared to women in their 20s and 30s. One report[10]. Indicated that the area and volume of the bottom of breasts increases with aging. In particular, the breasts of adult women with subcutaneous fat have greater changes, compared to other parts of body as they age, and protrude in a curve on the front of the upper body[11]. In this respect, pressing the breasts fastens drooped breasts and thins the thickened breast tissues caused by obesity, which are important in reducing the exposure dose and improving the quality of breast images.

In the human body, aging is accompanied by regression, which causes scoliosis. Functional scoliosis appears with secondary symptoms caused by external reasons, whereas structural scoliosis is caused by problems with the spine itself and has no specific reason[12]. Women with scoliosis have several limitations in mammography. For example, when a protruded chest caused by a bent spine presses the breasts, it can cause friction against the surface of the compression paddle on the chest wall side and not all of the breast tissue is included in the images. It is because the model of the conventional compression paddle is rectangular to fit the size of the receptor, and the edges of the rectangle are curved. The part that touches the chest wall is a straight line parallel with the end of the receptor, which does not fit a round chest, and is eventually pushed out by the chest. This prevents the inner and outer parts of the breasts from being included in the images. This is noticeable in patients with pectus carinatum or in patients with scoliosis whose chests are protruded. The chest of patients with pectus carinatum is naturally excessively protruded and these patients are likely to have a malformation in their spine.

Pectus carinatum is more common in male individuals, although it is not difficult to find female patients with pectus carinatum who visit hospitals for mammography. This is because scoliosis caused by regression, which occurs in women in their 40s and 50s, is accompanied by pectus carinatum. If too much breast tissue is pulled and placed on the receptor to include as much breast tissue of the patients with pectus carinatum, patients will complain of severe pain because the compression paddle will press the chest together. There is a report of a method in which semipermeable pads are used to reduce the pain of pressure; however, the structural problems of the compression paddle are not fully resolved, although the pain diminishes a little[13]. When applied to patients with scoliosis, the new compression paddle developed in this study is expected to reduce the compression and reduce the image quality, thus broadening the scope of diagnosis.

Dustler[14] et al. suggested a method in which images are acquired through partial pressure, excluding the chest part that prevents pressure and causes pain. This method can mitigate pain by removing pressure deterrents, but unstable factors that hinder breast cancer detectability increase because 1 cm of tissue cannot be obtained from the images. In the current study, the pain of pressure is reduced and 1 cm of tissue is visible.

There is an ongoing effort to improve the compression paddles because of pain in mammography and because the pressure is not evenly applied to all parts of the breasts. In particular, the pressure is not evenly applied to whole parts of breasts because of breast parenchymal tissues; therefore, it is recommended to correct the slope of the compression paddle to supplement[15,16]. References show that, Kallenberg and Karssemeijer and Kallenberg[17,18] et al. corrected the slope of the compression paddle by making the breast compression paddle movable, and on comparing it with the conventional compression paddle, they showed that images had more even concentration for the whole breast, compared to images made using the conventional compression paddle. References show that Liberman et al., Kirstein et al. and Burkholder et al. reported the difficulty of pressing the open window when locating a lesion before surgery and obtaining good quality of images[19,20,21]. Reference shows that Blane et al. devised a new compression paddle that can apply pressure in wire localization, and succeeded in achieving substantially improved images than those with the conventional paddle[22]. However, he could not improve the phenomenon in which portions of breast tissue were missing because of friction against the compression paddle caused by the structure of the human body.

Pressing the breasts in mammography is important for image quality and with regard to the exposure dose to patients[23]. References show Dibble et al., Coryell and Jaeger et al. reported that pressing the breast tissues on top of the radiolucent cushion can reduce the pain of patients and enhance the quality of images[24,25,26]. However, Hendrick and Hall reported that, although using a radiolucent cushion can increase image quality and can include as much breast tissue as possible, the exposure dose increases with increasing thickness[27]. Using the compression paddle for the tests conducted in this study can include as much breast tissue as possible without causing the problem of the exposure dose because its thickness is the same as that of the conventional paddle.

Conducting tests using the compression paddle developed in this study can solve the problem of pain experienced when the compression paddle presses on the chest as much as the protruded chest pushes out the compression paddle. The surface of the compression paddle that touches the chest is round; therefore, it allows more of the inner and outer parts of the breasts to be placed on the receptor and more tissue is included in the images. Therefore, the newly developed compression paddle is expected to resolve the problems better than the conventional compression paddles used in clinical practice.

This was a study on a compression paddle that was used for accurate diagnosis in mammography. A compression paddle model was developed to improve the imaging of breast tissues adjacent to the chest, which are difficult to include in images obtained with the conventional compression paddles, and its utility was evaluated. The newly developed compression paddle acquired images from 10 patients with pectus carinatum and evaluated the whole area of breast tissue, the length of the PNL, the length of breast on the chest wall side, and image flatness.

Conclusion

The necessary form of the compression paddle in mammography is a structural problem and some parts of the breast tissues adjacent to the chest wall can be missing in images. However, the newly developed breast compression paddle has a streamlined shape, which reduces the friction against the chest wall and includes the parts that could not be included previously, which allows testing of a broader area. The newly developed compression paddle has mobility with the spring equipment installed and moves back and forth to adjust to the size of the chest wall, which allows more breast tissue to be included. This study involved 10 patients with pectus carinatum. Therefore, the newly developed paddle may cause problems when applied to patients with different body types. Based on the result of this study, further research is needed to make effective use of the newly developed compression paddle.

Ethical Clearance: Not required

Source of Funding: Self

Conflict of Interest: Nil

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