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EVALUATION OF IMAGE QUALITY OF IVUS USING THE DEVELOPED QUALITY MEASURING METHOD

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ABSTRACT

Background/Objectives: *Studies on the characteristics and advantages and disadvantages of intravascular ultrasound (IVUS) have been relatively well progressed so far. However, prior studies on image quality measurement using the recently introduced 60 MHz and 40 MHz catheters are insufficient. Therefore, we conducted a comparative analysis study on the difference in acoustic impedance and resolution and contrast quality of images using the image quality measurement method devised by the researchers.*

Methods/Statistical analysis: *The ultrasonic body equipment used POLARIS. For the analysis, images of the end-systolic section, which are the easiest to evaluate vascular lesions when using IVUS, were acquired and captured, and each value was compared and analyzed. The ultrasonic catheters used were Opticross™ HD 60 MHz and Opticross™ 40 MHz. As the target images, ultrasound images performed during 87 percutaneous coronary intervention were selected and analyzed for normal vessels with vessel sizes of 3.0 mm to 4.0 mm and lesion vessel images.*

Findings: *As a result of analyzing the difference in acoustic impedance in the normal lumen area and fibro-fatty area of the 40 MHz and 60 MHz catheters, In the difference in shade brightness, the 40 MHz catheter than the 60 MHz catheter had a statistically significantly higher on both the normal area and fibro-fatty area for impedance difference ($p<0.05$). As a result of analyzing the resolution (SNR) and contrast (CNR) of the normal lumen area, the 60 MHz catheter (-3.695±1.303) than the 40 MHz catheter (-4.297±0.643) had a higher SNR by 0.602±0.661 which was statistically significant. The results of the contrast analysis were not statistically significant. In the resolution and contrast analysis of the fibro-fatty area, signal of 60 MHz catheter (-2.466±0.659)than the 40 MHz catheter was higher (-3.245±0.553) by 5.79±0.106 and was statistically significant. In contrast analysis, the 40 MHz catheter was higher than the 60 MHz catheter by 0.032±0.005 and was statistically significant ($p<0.001$).*

Improvements/Applications: *In conclusion, if IVUS is used, 60 MHz catheter is considered good for obtaining images of high resolution quality. And i think it is good to use a 40 MHz catheter to obtain a being high intensity acoustic impedance difference and a good contrast difference. In the end, when selecting an IVUS catheter, which is an auxiliary device for interventional procedures, the method used in the right place according to the information the operator wants to obtain is considered to be the method of selecting the correct surgical auxiliary device. Therefore, it is thought that the results of this study can serve as a basis for rational evaluation for subsequent studies by presenting the objective evaluation results of image quality according to the difference in ultrasound catheter frequency.*

Keywords: *Percutaneous Coronary Intervention (PCI), Intravascular Ultrasound (IVUS), Signal to Noise Ratio (SNR), Contrast to Noise Ratio (CNR)*

1. INTRODUCTION

Since the 1950s, due to the miniaturization of ultrasonic probes[1], the applicable organs have also been diversified according to the size and purpose of creation until now[2,3]. Moreover, efforts to design an IVUS with electrodes for electrocautery are continuing to develop into a vast area[4].

In particular, the IVUS catheter used for coronary artery examination corresponds to a representative miniaturized ultrasound. In this case, a subtle difference may be shown in the visually expressed image quality depending on the difference in the applied frequency[5,6]. In fact, the lesion evaluation method using IVUS classifies the shape of the lesion based on the external elastic membrane (EEM) according to the guidelines of the American Heart Association report[7] Based on this standard, using the measurement method devised by the research team, we analyzed how much the visually significant difference in acoustic impedance is numerically and what significant difference the difference in resolution and contrast quality shows. Additionally, according to the density of the medium, the acoustic impedance of each component of the atherosclerotic plaque, such as adipose tissue, fibrous tissue, and calcified tissue, is different by using the phenomenon[8,9] of difference in brightness differences in brightness and resolution and contrast were also compared and analyzed.

2. MATERIALS AND METHODS

2.1. Equipment and Objects

The intravascular ultrasound equipment used was POLARIS (Meditech/Boston Scientific Corporation, waterton, MA, USA), and the ultrasound catheter was Opticross™ HD (Opticross HD Coronary Imaging Catheter, Boston Scientific, EL Coyol-Alajuela, Costarica, USA). 60 MHz and Opticross™ (Opticross HD Coronary Imaging Catheter, Boston Scientific, EL Coyol-Alajuela, Costarica, USA) 40 MHz were used. The output program used for image transmission used the medical image transmission device software DCAS (DICAS I CS, Version DCAS I, Gpnp, cheondam-dong, Seoul). Image J image analysis program (Image J Ver. 1.46r, National Institutes of Health, USA) was used as a measurement and analysis program used to propose a method for measuring the image quality of intravascular ultrasound. Image J program is usefully used as a quantitative image quality measurement method as in the study of Seo Young-hyeon[10] and the image quality analysis study of Jeong Myo-young[11] As a characteristic, it is a method of providing a value by analyzing the pixels on the output screen and substituting them into the formula[12].

The images used in the study were IVUS images performed during percutaneous coronary angioplasty, and images of normal vessels and fibrofatty & fibrous plaque vessels with vessel sizes of 3.0 mm to 4.0 mm were analyzed. In particular, in a study comparing normal lumen area and fibrofatty area, group A (40 MHz) images consisting of 46 images and group B (60 MHz) images consisting of 41 images were randomly acquired and compared and analyzed. Table 1 shows the average age and average body mass index of the subjects.

Table 1. Result of descriptive statistics for patient

	Group A	Group B
Catheter	40 MHz	60 MHz
2 sample	n=46	n=41
3 sample	n=14	n=15
Vessel size	3.0 ~ 4.0	3.0 ~ 4.0
Age	63	67
BMI	25.711	24.459

2.2. Study Method and Image Acquisition Method

2.2.1. IVUS Default Condition Set up Method

The IVUS equipment basic setting conditions were saved by setting Depth 9, Brightness 6, Grid display on, Auto pull back speed 0.5 mm/sec, Near field suppression low, Far field suppression low, and Imaging mode to Standard, as shown in Table 2. In addition, before using IVUS, the ultrasound catheter was thoroughly washed to prevent air or foreign substances from entering, and the image taken after the blood vessel was sufficiently dilated by administering 200 micro of nitroglycerin (NTG) into the coronary artery was retrospectively performed through DCAS PACS. was obtained with Then, the image quality was compared and analyzed using the devised image quality measurement method.

Table 2. Condition set up of IVUS

	40 MHz	60 MHz
Depth (Db)	9	9
Brightness	6	6
Grid display	On	On
Auto pull back speed (mm/sec)	0.5	0.5
Near field suppression	Low	Low
Far field suppression	Low	Low
Imaging mode	Standard	Standard

2.2.2. Image Acquisition Method

We got IVUS images via image J program before coronary intervention (PCI). In particular, according to the Clinical application and image interpretation in IVUS study by C Di Mario et al[13], when using IVUS, the image of the end-systolic section, which is the easiest to evaluate vascular lesions, is acquired and captured, and then called into the Image J program to measure each value after comparative analysis. It same as Fig. 1.2.

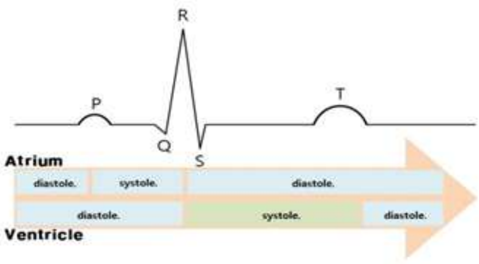

Fig. 1. State of heart according to ECG rhythm

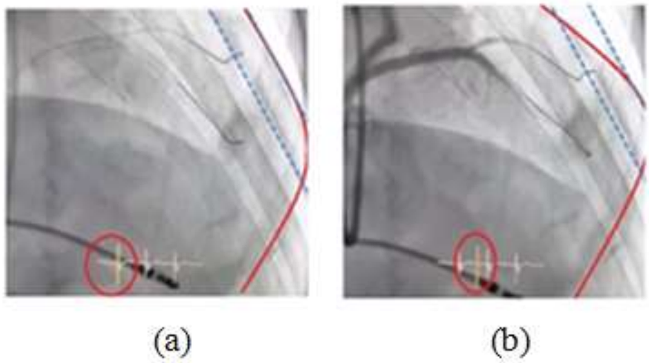

Fig. 2. Position of ECG rhythm and cardiac shadow shown in CAG according to systolic (a) and diastolic (b)

2.3. Image Measurement Method and Image Quality Evaluation Method

2.3.1. ROI and Background Measurement Method

In the method of measuring IVUS images, measured the region of interest and background using the Image J program according to the Development of a Method for Measuring Image Quality of Intra Vascular Ultrasound Images using Image Analysis Program of Seo Young-hyun [14], and the measured values were calculated into SNR and CNR.

2.3.2. SNR and CNR Evaluation Method

SNR and CNR are evaluated to have high signal-to-noise contrast when the value shows a large value because a larger value means less noise. Using this characteristic, the picture quality was evaluated using equations EP. (2) and EP. (3), and the relationship between noise per pixel is shown Same as EP. (1)[13].

$$\sigma = \sqrt{N} \quad (1)$$

(σ : standard deviation or noise)

As a method to obtain the SNR, the difference between the average value of the signal intensity of the region of interest was obtained from the average value of the signal intensity of the background region and divided by the standard deviation of the entire region of interest. It same as EP. (2)[13].

$$SNR = \frac{Background\ SI_{Avg} - ROI\ SI_{Avg}}{ROI\ SD} \quad (2)$$

In the case of CNR, it is a value indicating the contrast of the region of interest with respect to the surrounding noise, It same as Ep. (3), the difference between the average signal value of the region of interest was obtained from the average signal value of the background region, and then the standard deviation of the background region and the standard deviation of the region of interest was obtained and divided by the added value to calculate the CNR[15,16].

$$CNR = \left| \frac{Background\ SI_{Avg} - ROI\ SI_{Avg}}{\sqrt{Background\ SD^2 + ROI\ SD^2}} \right| \quad (3)$$

2.3.3. SNR and CNR Measurement Method

After selecting a specific site by applying the devised image measurement method, the SNR and CNR of the site were quantified using the Image J program, substituted into the above-mentioned formula, and statistical analysis was performed to derive the result.

2.4. Statistical Analysis Method

In the analysis using SPSS, the significance and image quality of the difference in shade impedance for each lesion and plaque discrimination according to SNR and CNR were evaluated through T-test and Mann-Whitney Test.

3. RESULTS AND DISCUSSION

3.1. Analysis of the Difference in Acoustic Impedance

3.1.1. Mann-Whitney Test Results for Normal Lumen and Fibrofatty and Fibrous Area of Group A and B

In the difference in the measured acoustic impedance of the normal lumen area, group A (40 MHz) was 80.32±12.58, which showed higher signal shading by 17.37±4.17 than group B (60 MHz) 62.95±8.41, and was statistically significant (p<0.001). It same as Table 3.

In the difference in the measured acoustic impedance of the fibrofatty area, group A (40 MHz) was 95.97±14.2, which was 16.04±0.93 higher than group B (60 MHz) 79.93±15.13, and was statistically significant (p<0.05). It same as Table 3.

In the difference in the measured acoustic impedance of the fibrous area, group A (40 MHz) showed 143.99±15.37, which was 3.95±3.52 higher than group B (60 MHz) 140.04±11.85, but it was not statistically significant (p> 0.05) It same as Table 3 and Fig. 3.

Table 3. Measurement value present as a result of Mann-Whitney Test

Area	Group A (40 MHz)	Group B (60 MHz)	p
normal	80.32±12.58	62.95±8.41	p<0.001
fibrofatty	95.97±14.2	79.93±15.13	p<0.05
fibrous	143.99±15.37	140.04±11.85	p>0.05

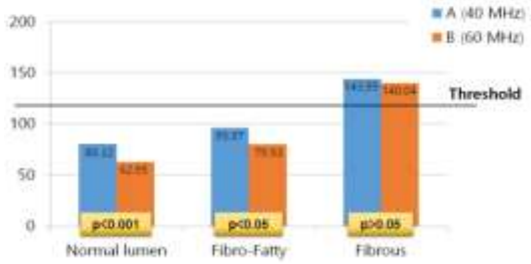

Fig. 3. Acoustic impedance difference histogram of normal lumen, fibrofatty and fibrous area for inside of adventitia

3.1.2. Mann-Whitney Test Results for Adventitia Area of Normal Lumen and Fibrofatty and Fibrous area of Group A and B

In the difference in the measured acoustic impedance of the adventitia area of normal lumen area, group A (40 MHz) 118.38±10, which was 12.99±8.2 higher than group B (60 MHz) 105.39±18.20, and was statistically significant (p<0.05). It same as Table 4.

In the difference in the measured acoustic impedance of the adventitia area of fibrofatty area, group A (40 MHz) showed 116.61±11.48, which was 12.99±2.03 higher than group B (60 MHz) 100.87±13.51, and was statistically significant (p<0.05). It same as Table 4.

In the difference in the measured acoustic impedance of the adventitia area of fibrous area, group A (40 MHz) was 119.37±11.95, which was brighter by 13.92±2.54 than group B (60 MHz) 105.45±14.49, and was statistically significant (p<0.05). It same as Table 4 and Fig. 4.

Table 4. Measurement value present as a result of Mann-Whitney Test

Adventitia area	Group A (40 MHz)	Group B (60 MHz)	p
Normal	118.38±10	105.39±18.20	p<0.05
Fibrofatty	116.61±11.48	100.87±13.51	p<0.05
Fibrous	119.37±11.95	105.45±14.49	p<0.05

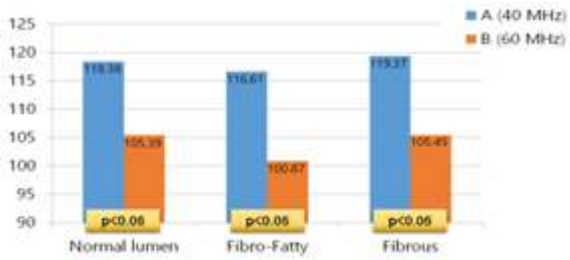

Fig. 4. Acoustic impedance difference histogram of normal lumen, fibrofatty and fibrous area for outside of adventitia area

3.2. Analysis of the SNR and CNR

3.2.1. T-test Results of SNR and CNR in Normal Lumen Area of Group A and B

As a result of comparative analysis of normal lumen area SNR, the SNR of group B (60 MHz) (-3.695±1.303) was higher than that of group A (40 MHz) (-4.297±0.643) by 0.602±0.661 and was statistically significant (p<0.05).). It same as Table 5 and Fig. 5.

As a result of comparative analysis of normal lumen area CNR, the CNR (0.235±0.132) of group B (60 MHz) was higher than the CNR (0.235±0.052) of group A (40 MHz) by

0±0.08, but it was not statistically significant (p>0.05).). It same as Table 5 and Fig. 5.

Table 5. Measurement value present as a result of T-test

Normal area	Group A (40 MHz)	Group B(60 MHz)	p
SNR*	-4.297±0.643	-3.695±1.303	p<0.05
CNR**	0.235±0.052	0.235±0.132	p>0.05
SNR: Signal to Noise Ratio asterisk(*), CNR: Contrast to Noise Ratio double asterisk(**)			

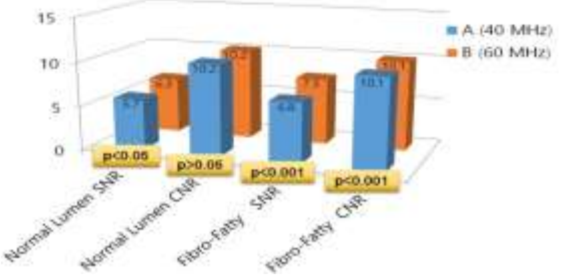

Fig. 5. SNR and CNR difference histogram of normal lumen and fibrofatty area for inside of adventitia

3.2.2. T-test Results of SNR and CNR in Fibrofatty Area of Group A and B

As a result of the fibrofatty area SNR comparison analysis, the SNR (-2.466±0.659) of group B (60 MHz) was higher than that SNR (-3.245±0.553) of group A (40 MHz) by 5.79±0.106 and was statistically significant (p<0.001). It same as Table 6 and Fig. 5.

As a result of comparative analysis of fibrofatty area CNR, the CNR (0.119±0.037) of group A (40 MHz) was higher than that of CNR(0.087±0.032) of group B (60 MHz) by 0.032±0.005 and was statistically significant (p<0.001). It same as Table 6 and Fig. 5.

Table 6. Measurement value present as a result of T-test

Fibrofatty area	Group A (40 MHz)	Group B(60 MHz)	p
SNR	-3.245±0.553	-2.466±0.659	p<0.001
CNR	0.119±0.037	0.087±0.032	p<0.001

3.2.3. T-test Results of SNR and CNR for Adventitia Area in Normal Luemn of Group A and B

As a result of comparative analysis of the Adventitia area of normal lumen area SNR, the SNR (-4.376±1.261) of group B (60 MHz) was higher than that SNR (-5.172±1.087) of group A (40 MHz) by 0.796±0.174 and was statistically significant (p<0.05). It same as Table 7 and Fig. 6.

As a result of comparative analysis of adventitia area of normal lumen area CNR, CNR (0.235±0.837) of group A (40 MHz) was higher than that CNR (0.167±0.063) of group B (60 MHz) by 0.068±0.774 and was statistically significant (p< 0.001). It same as Table 7 and Fig. 6.

Table 7. Measurement value present as a result of T-test

Adventitia (norma area)	Group A (40 MHz)	Group B(60 MHz)	p
SNR	-5.172±1.087	-4.376±1.261	p<0.05
CNR	0.235±0.837	0.167±0.063	p<0.001

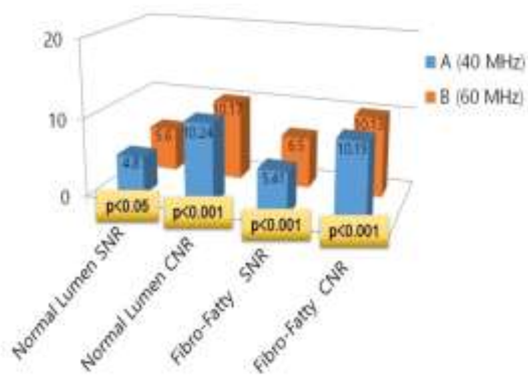

Fig. 6. SNR and CNR difference histogram of normal lumen and fibrofatty area for outside of adventitia

3.2.4. T-test Results of SNR and CNR for Adventitia Area in Fibrofatty of Group A and B

As a result of comparative analysis of Adventitia area of fibrofatty area SNR, the SNR (-3.497±1.033) of group B (60 MHz) was higher than that SNR (-4.586±0.892) of group A (40 MHz) by 1.089±0.141 and was statistically significant (p <0.001). It same as Table 8 and Fig. 6.

As a result of comparative analysis of Adventitia area of fibrofatty area CNR, CNR (0.185±0.067) of group A (40 MHz) was higher than that CNR (0.125±0.053) of group B (60 MHz) by 0.06±0.014 and was statistically significant (p<0.001).) It same as Table 8 and Fig. 6.

Table 8. Measurement value present as a result of T-test

Adventitia (fibrofatty area)	Group A (40 MHz)	Group B(60 MHz)	p
SNR	-4.586±0.892	-3.497±1.033	p<0.001
CNR	0.185±0.067	0.125±0.053	p<0.001

3.3. DISCUSSION

Medical ultrasound generally uses frequencies in the range of 1 to 15 MHz, but some special ultrasound applications exceed 50 MHz[17]. The IVUS catheters currently used herein are 40 MHz and 60 MHz catheters, which can be included in special ultrasound applications. As a feature of the mentioned frequency, the frequency has a characteristic that depends on the density[18], which affects the acoustic resistance according to the density of the tissue. and as a result, various conclusions could be reached. First, in the results of analyzing the difference in acoustic impedance between 40 MHz and 60 MHz catheters, the 40 MHz catheter showed a statistically significant difference in shade than the 60 MHz catheter. According to the study of P. J. Jung[17], under the same conditions, the higher the frequency and the deeper the deeper, the more severe the attenuation. It could be confirmed that the sound difference of the signal was indicated. Second, among the acoustic impedance classification according to the type of organized lesion, both 40 MHz and 60 MHz catheters showed high-signal images by increasing the acoustic impedance of the vessel lumen as the density increased from normal blood vessels to fibrous tissues. The acoustic impedance of the extravascular space (EEM) showed a statistically insignificant shade difference regardless of the lesion type characteristics. result, as discussed in the report of the American Heart Association[6], it was confirmed once again that the method of distinguishing the softness and fibrousness of the lesion by the difference in brightness according to the acoustic impedance based on the EEM was theoretically established. Third, the 60 MHz catheter showed excellent resolution regardless of the shape of the lesion in both the lumen and the external lumen (EEM) among the image quality measurements regarding the resolution, which indicates that the frequency representing the performance of the probe is inversely proportional to the wavelength. It is believed that this is the result of the characteristic that the transmittance decreases and the resolution increases as the frequency is raised[19]. Conversely, in contrast, the 40 MHz catheter performed better than the 60 MHz catheter in all areas except the normal lumen area. Because the contrast difference is insignificant in the normal vascular lumen region, the 40 MHz characteristic shows a stronger signal at higher density. I think it's the result of not being able to show the characteristics. Therefore, in the case of a low-frequency (40 MHz) catheter, it can be expressed that it is easy to distinguish a lesion using a contrast difference because the contrasting difference is clear in a lesion in a high-density state such as a soft plaque lumen. In the case of lesions, it is thought that the more correct way of expression is to distinguish by mentioning that the brightness of the shade rather than the contrast is described as a higher signal. In particular, since there was no significant difference in acoustic impedance in the EEM region, it is judged that it is ok to select a cathetr of any frequency when classifying the shape of the lesion according to the brightness based on the EEM. That is, in selecting a catheter according to the image quality classification, it is considered that a high frequency (60 MHz) catheter should be selected to obtain a high resolution image, and a low frequency (40 MHz) catheter should be selected to obtain a high contrast image. In order to classify the classification according to the type of lesion, it is judged that it is appropriate to use a catheter with a low frequency (40 MHz).

A limitation of this study was that a total of 87 images were comparatively analyzed, but it was a pity that more image samples could not be obtained. Nevertheless, there was no difficulty in proceeding with the study because appropriate statistical methods were used. Additionally, as it has been less than a year since the 60 MHz catheter was introduced in Korea, the lack of prior research was a difficulty in the study. Also, there were many trials and errors as the researchers in Korea devised and applied the method for measuring the quality of IVUS images for the first time. Nevertheless we think was able to overcome it thanks to other previous studies using the J program[10,11]. In addition, Seo Young-hyun's[14] previous research on the method of measuring image quality was registered in the Journal of the Korean Radiological Society, thereby increasing the reliability of the research.

Lastly, during the comparison analysis of the quality of the low-frequency (40 MHz) catheter and the high-frequency (60 MHz) catheter for 2 samples, only the normal lumen and the soft plaque lumen were compared and analyzed, excluding the fibrous plaque lumen image. For a reason in case of proceeding beyond the fibrofatty stage , it was judged meaningless to compare because all of them showed similarly high values when exceeding a specific acoustic impedance value, that is, a threshold value. As such, IUVS catheter is a device that visualizes the inside of blood vessels, that is, an invisible area, so research on image quality should be continuously conducted in line with the continuously developed and improved equipment. Therefore, if the image quality measurement method devised by this research team is applied to various IVUS equipment and used, information on image quality change according to frequency can be obtained more efficiently in new products to be released in the future.

4. CONCLUSION

In conclusion, if IVUS is used, 60 MHz catheter is considered good for obtaining images of high resolution quality. And i think it is good to use a 40 MHz catheter to obtain a being high intensity acoustic impedance difference and a good contrast difference. In the end, when selecting an IVUS catheter, which is an auxiliary device for interventional procedures, the method used in the right place according to the information the operator wants to obtain is considered to be the method of selecting the correct surgical auxiliary device. Therefore, it is thought that the results of this study can serve as a basis for rational evaluation for subsequent studies by presenting the objective evaluation results of image quality according to the difference in ultrasound catheter frequency.

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