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A Comparison between Portal Dosimetry and Mobius3D Results for Patient-Specific Quality Assurance in Radiotherapy

Sung Yeop Kim[1], Jaehyeon Park[2,3], Jae Won Park[2,3], Ji Woon Yea[2,3], Se An Oh[2,3]

[1]Department of Physics, Yeungnam University, Gyeongsan, [2]Department of Radiation Oncology, Yeungnam University Medical Center, [3]Department of Radiation Oncology, Yeungnam University College of Medicine, Daegu, Korea

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Corresponding author
Se An Oh
(sean.oh5235@gmail.com)
Tel: 82-53-620-3054
Fax: 82-53-624-3599

Purpose: The purpose of this study was to compare the clinical quality assurance results of portal dosimetry using an electronic portal imaging device, a method that is extensively used for patient-specific quality assurance, and the newly released Mobius3D for intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT).

Methods: This retrospective study includes data from 122 patients who underwent IMRT and VMAT on the Novalis Tx and VitalBeam linear accelerators between April and June 2020. We used a paired t-test to compare portal dosimetry using an electronic portal imaging device and the average gamma passing rates of MobiusFX using log files regenerated after patient treatment.

Results: The average gamma passing rates of portal dosimetry (3%/3 mm) and MobiusFX (5%/3 mm) were 99.43%±1.02% and 99.32%±1.87% in VitalBeam and 97.53%±3.34% and 96.45%±13.94% in Novalis Tx, respectively. Comparison of the gamma passing rate results of portal dosimetry (3%/3 mm) and MobiusFX (5%/3 mm as per the manufacturer's manual) does not show any statistically significant difference.

Conclusions: Log file-based patient-specific quality assurance, including independent dose calculation, can be appropriately used in clinical practice as a second-check dosimetry, and it is considered comparable with primary quality assurance such as portal dosimetry.

Keywords: Patient-specific quality assurance, Mobius3D, Electronic portal imaging device, Intensity-modulated radiotherapy, Volumetric modulated arc therapy

Introduction

Complex radiation techniques, such as intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT), have been developed for delivering the desired radiation dose to a tumor with minimum radiation to the surrounding normal organs [1-6]. Currently, IMRT and VMAT are among the most widely used radiation therapy techniques [7,8]. However, these complex radiation treatment modalities require commissioning and quality assurance (QA) [9-12]. A second-check dosimetry system is used for detecting treatment planning errors due to software malfunctions, errors when implementing specific algorithms in the treatment planning system (TPS), or structural defects in specific parameters. Accordingly, this second-check system assesses these issues using an algorithm that is different from the primary TPS [13].

Patient-specific QA for complex radiotherapy techniques,

such as IMRT and VMAT, has become increasingly important, something that has been verified by various IMRT QA tools [14]. Previously, patient-specific QA was performed using an ionization chamber, film, and thermoluminescence dosimeter, which were used for the verification of the calculated and delivered radiation doses [10,15-18]. Currently, patient-specific QA for complex radiotherapy techniques, such as IMRT and VMAT, is performed with a two-dimensional (2D) array and an electronic portal imaging device (EPID) [10,19-21].

Mobius3D and PerFRACTION (Sun Nuclear Corporation, SNC, Melbourne, FL, USA) are both commonly used second-check dosimetry systems. These two dosimetry systems have different three-dimensional (3D) dose reconstruction methods: Mobius3D performs reconstruction using log files only, whereas PerFRACTION uses log files and EPID images as well. As for the difference in the algorithm used, Mobius3D uses a collapsed cone (CC) convolution algorithm, whereas PerFRACTION uses a superposition/convolution GPU-accelerated dose computation algorithm [22].

Mobius3D was recently released as a second-check dosimetry system that is independent of the primary TPS. This system is a novel commercial log file-based online system that provides a comprehensive patient-specific QA program. Planning and delivery are verified using an independent three-dimensional dose calculation algorithm and treatment log files [23-26].

Previous studies have evaluated the characteristics of Mobius3D and reported the related commissioning results. However, a limited number of clinical performance evaluations of this system have been performed [23-26]. To overcome this shortfall, our study used data from many patients (n=122) to confirm that this independent second-check dosimetry system can be clinically used in both VitalBeam (Varian Medical System) and Novalis Tx linear accelerators (Varian Medical System).

We evaluated the patient-specific QA results obtained using the newly released Mobius3D and EPID, which are extensively used for patient-specific QA, in both IMRT and VMAT.

Materials and Methods

1. Study design and participants

This study was a retrospective data analysis consisting of 122 patients who underwent IMRT and VMAT on the Novalis Tx and VitalBeam linear accelerators between April and June 2020. The following cases were excluded: 1) patients who received simple radiotherapy, such as 2D radiotherapy or three-dimensional conformal radiotherapy and 2) patients who performed patient-specific quality control with either EPID or Mobius3D but not with both.

2. Treatment planning and delivery techniques

All radiation treatment plans were generated using eclipse ARIA 15.6 (Varian Medical System) for delivering the desired radiation to tumors with minimal radiation to the surrounding normal tissues. The analytical anisotropic algorithm (AAA) was used as the calculation algorithm, and beam arrangement was selected to ensure delivery of minimum radiation to vital organs. All confirmed treatment plans were exported simultaneously into ARIA and Mobius3D. Seventy-six cases (62.3%) underwent VMAT, and 46 cases (37.7) underwent IMRT with a fixed gantry. Furthermore, 65 cases (53.3%) used VitalBeam, and 57 cases (46.7%) used Novalis Tx.

3. Mobius3D

Mobius3D includes the following four modules: (1) MobiusCalc for 3D plan QA, (2) MobiusFX for 3D IMRT/VMAT and daily treatment QA for all factions, (3) MobiusCB for patient CBCT QA, and (4) DoseLab for machine QA [25]. Mobius3D independently recalculates the radiation dose for patient CT datasets using a CC algorithm and treatment parameters (structure sets, field sizes, gantry angles, couch angles, beam energy, monitor unit [MU], and MLC data) that are exported from the primary TPS. In addition, MobiusFX provides QA for treatment plans using Mobius3D models and the generated log files delivered from the treatment machines. In this study, the difference between the dose distribution planned by MobiusCalc and the dose dis-

tribution replanned by MobiusFX using log files generated after clinical radiation treatment were analyzed through gamma analysis [25,27].

4. Commissioning of Mobius3D

Mobius3D was released as a second-check dosimetry system, and it was designed to perform secondary dose calculations using the standard reference beam dataset of a specific linear accelerator. Users can customize beam data, such as off-axis ratios, output factors, and depth dose values, to better suit Mobius3D's modeling. However, the manufacturer recommends minimal customization to ensure the independence of the secondary dosimetry system [23,25]. Therefore, Yeungnam University Medical Center uses the standard reference beam dataset in accordance with the manufacturer's recommendation. When analyzing the gamma index, 5%/3 mm is applied as per the commissioning guideline.

For targets that are steadily hot or cold in the IMRT or VMAT plans, the dosimetric leaf gap (DLG) correction factor can be adjusted for each machine and energy level. The internal DLG value is invisible to the user, and it is basically built-in for beam models in Mobius. The DLG correction factor is a value for correcting the internal DLG with ion chamber measurements. DLG correction factor is recommended to be corrected through measurement using an ion chamber. If the DLG value is positive, the calculated dose increases, and vice versa. If the average dose differs by more than 2%, the machine's DLG factor must be adjusted. The plan is recalculated and then repeated until the dose is within 2%. To optimize the procedure for adjusting the DLG correction factor, we downloaded the DLG correction factor optimization spreadsheet (mobiusmed.com/support). The DLG was optimized on the basis of the linear regression method. All test plans used for commissioning were applied to VMAT plans and included prostate, head and neck, Lt lung, Rt lung large, and Rt lower lobe lung regions. The optimal DLG value was obtained by entering the radiation dose value measured in the ionization chamber. The calculated dose value was obtained using the Mobius verification phantom™. Table 1 shows the DLG correction factor calculated from the optimization spreadsheet. In addition, Fig. 1 depicts the regression model using the MobiusFX ionization chamber measurement vs. the DLG for Novalis Tx with 6 MV (R^2=0.9948).

5. Electronic portal imaging device

Portal dosimetry was used to evaluate the measured fluence using the EPID attached to the linear accelator [27]. Previous studies have reported that portal dosimetry can be used extensively and appropriately for patient-specific QA

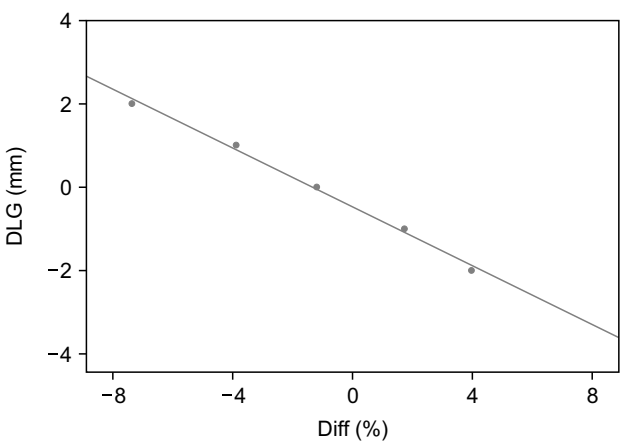

Fig. 1. Regression model using the MobiusFX ionization chamber measurement vs. the dosimetric leaf gap (DLG) for Novalis Tx with 6 MV (R^2=0.995).

Table 1. DLG correction factor calculated from the optimization spreadsheet (obtained from mobiusmed.com/support)

Machine	Energy (MV)	Optimal DLG (mm)	Linear fit (R^2)
Novalis Tx	6	0.47	1.0000
	15	−2.01	1.0000
VitalBeam	4	−0.94	1.0000
	6	−0.47	0.9948
	10	−0.70	1.0000
	6 MV_FFF	−0.85	0.9999

DLG, dosimetric leaf gap; FFF, flattening filter free.

in IMRT and VMAT treatments. Moreover, it can be used routinely in pretreatment QA, interchangeably with 2D array systems [28,29]. Our institution routinely verifies all IMRT and VMAT treatment plans and measures the radiation doses through portal dosimetry using an EPID with a gamma criterion of 3%/3 mm for patient-specific QA. The experimental setup with portal dosimetry using an EPID for patient-specific QA on Novalis Tx is shown in Fig. 2.

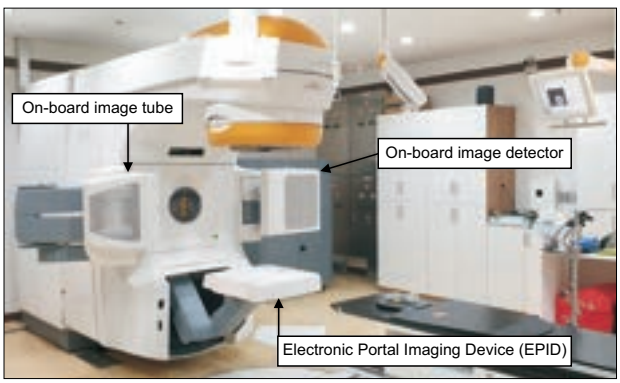

Fig. 2. Experimental setup with portal dosimetry using an EPID for patient-specific quality assurance on Novalis Tx.

6. Analysis of the gamma index between Mobius3D and electronic portal imaging device dosimetry

The gamma index (3%/3 mm) obtained through portal dosimetry, which is extensively used in clinical practice, was analyzed using treatment-related factors, such as field size, beam on time, and monitor unit. From the log files generated by MobiusFX, the statistical difference was determined for values such as the gamma index (5%/3 mm), X1, X2, Y1, Y2, collimator, and gantry. Fig. 3 displays the gamma analysis image for assessing the difference between the treatment plan generated by MobiusCalc and the treatment plan regenerated by MobiusFX using log files generated after clinical radiation treatment. Fig. 4 depicts the gamma analysis of the predicted dose by TPS and the portal dose measured through EPID.

7. Statistical analyses

SPSS statistical software version 22 (IBM Corp., Armonk, NY, USA) was used, and a paired t-test was performed,

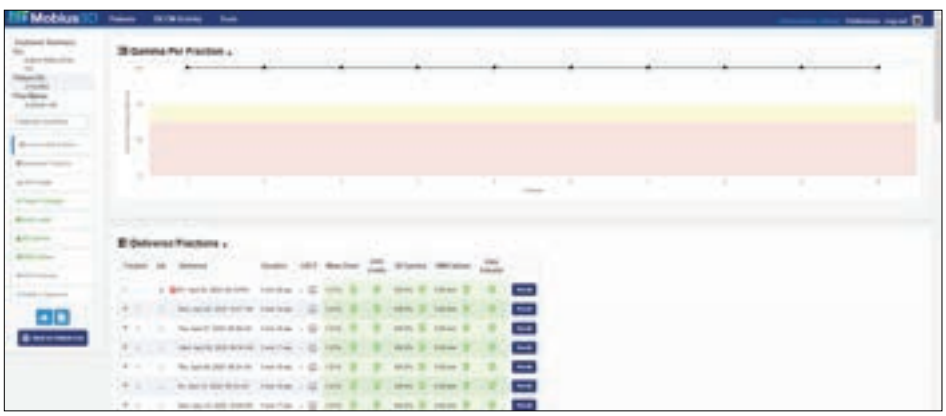

Fig. 3. Gamma analysis image for the determination of the difference between the dose distribution planned by MobiusCalc and the dose distribution replanned by MobiusFX using the log files generated after clinical radiation treatment.

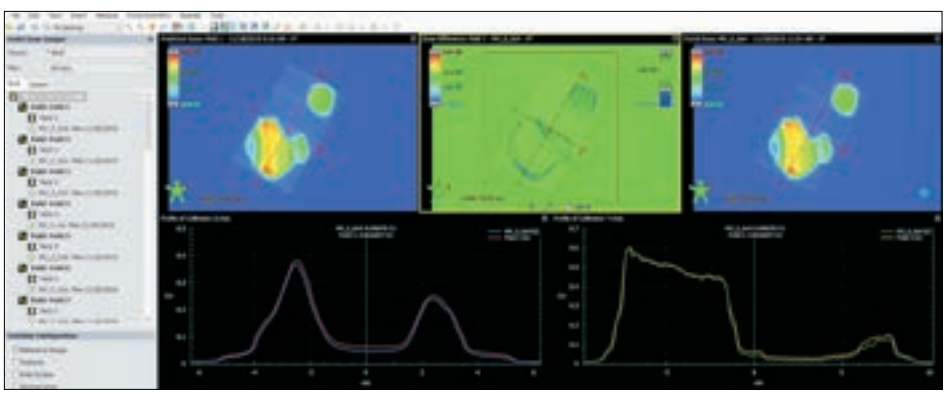

Fig. 4. Gamma analysis of the predicted dose by the treatment planning system and the portal dose measured using electronic portal imaging device.

where $P<0.05$ was considered statistically significant.

Results

Patient and treatment characteristics are described in Table 2. The study included 48 (39.3%) female and 74 (60.7%) male patients, with an average age of 64 years (range, 25–87 y). Paired t-test results indicating the differences between portal dosimetry and MobiusFX in patient-specific QA for IMRT and VMAT are presented in Table 3. For Novalis Tx and VitalBeam, portal dosimetry (3%/3 mm) and portal dosimetry (5%/3 mm) showed statistically significant *P*-values of <0.001 and <0.001, respectively.

Table 2. Patients and treatment characteristics included in this study

Characteristic	Value
Patient	
Number of patients	122
Age (y)	64 (25–87)
Sex	
Female	48 (39.3)
Male	74 (60.7)
Treatment region	
Brain	15 (12.3)
Head and neck	8 (6.6)
Lung	29 (23.8)
Breast	25 (20.5)
Abdomen	18 (14.8)
Pelvis	27 (22.1)
Treatment	
Technique	
IMRT	46 (37.7)
VMAT	76 (62.3)
LINAC machine	
VitalBeam	65 (53.3)
Novalis Tx	57 (46.7)

Values are presented as number only, median (range), or number (%).
IMRT, intensity-modulated radiotherapy; VMAT, volumetric modulated arc therapy; LINAC, linear accelerator.

For Novalis Tx, the average gamma index values of portal dosimetry (3%/3 mm) and MobiusFX (5%/3 mm) were 97.53%±3.34% and 96.45%±13.94%, respectively. The average values of portal dosimetry (3%/3 mm) and MobiusFX (5%/3 mm) for VitalBeam were 99.43%±1.02% and 99.32%±1.87%, respectively. The results of the paired t-test between portal dosimetry (3%/3 mm) and MobiusFX (5%/3 mm) were 0.571 for Novalis Tx and 0.678 for VitalBeam and did not show any statistical difference.

The correlation between MobiusFX (5%/3 mm) and portal dosimetry (3%/3 mm) for patient-specific QA with Novalis Tx and VitalBeam are shown in Fig. 5. Therefore, it is essential to clinically determine the portal dosimetry (3%/3 mm) criteria, which are commonly used in patient-specific QA for IMRT and VMAT, by applying the 5%/3-mm criterion when using MobiusFX.

The result of portal dosimetry (3%/3 mm) used in patient-specific QA was statistically similar to the paired t-test of the QA result of MobiusFX (5%/3 mm).

Table 3. Comparison between the gamma passing rate results of PD and MobiusFX for patient-specific QA in IMRT and VMAT

LINAC machine	Factor	Gamma passing rates (%)	Difference between paired data		
			Mean±standard deviation	Standard error	*P*-value of paired t-test
Novalis Tx					
#1	PD (3%/3 mm)	97.53±3.34	−2.07±2.95	0.39	<0.001
	PD (5%/3 mm)	99.61±0.74			
#2	PD (3%/3 mm)	97.53±3.34	1.07±14.27	1.89	0.571
	MobiusFX (5%/3 mm)	96.45±13.94			
VitalBeam					
#1	PD (3%/3 mm)	99.43±1.02	−0.49±0.86	0.10	<0.001
	PD (5%/3 mm)	99.92±0.22			
#2	PD (3%/3 mm)	99.43±1.02	0.10±2.05	0.25	0.678
	MobiusFX (5%/3 mm)	99.32±1.87			

PD, portal dosimetry; QA, quality assurance; IMRT, intensity-modulated radiotherapy; VMAT, volumetric modulated arc therapy; LINAC, linear accelerator.

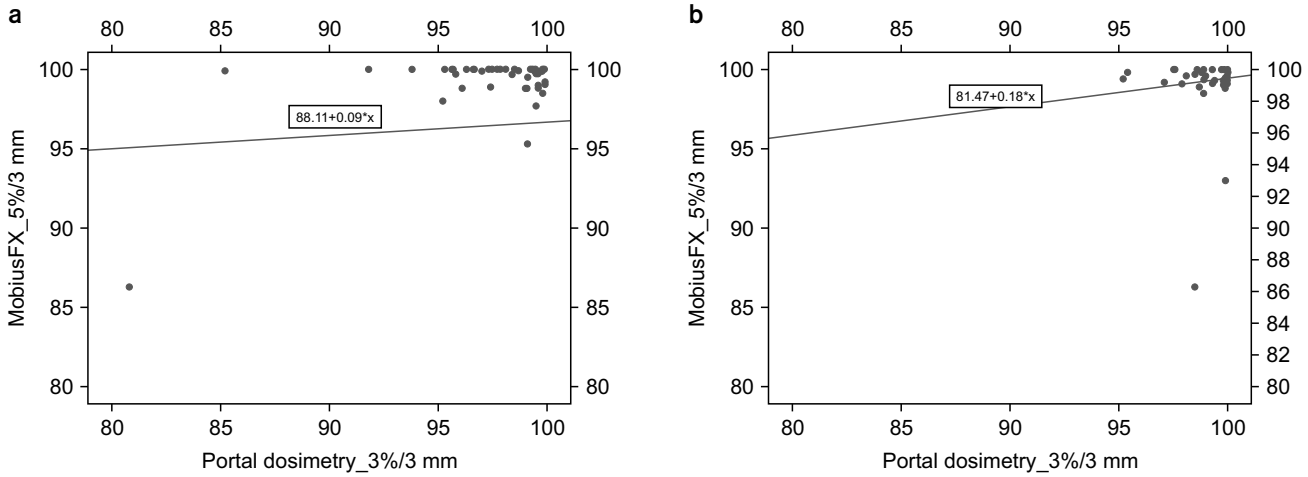

Fig. 5. Correlation between MobiusFX (5%/3 mm) and portal dosimetry (3%/3 mm) for patient-specific quality assurance: (a) Novalis Tx and (b) VitalBeam.

Discussion

Unlike conventional radiation treatment techniques, the latest radiotherapy techniques, such as IMRT and VMAT, have complex dose distributions and steep dose gradients. Currently, as these radiotherapy techniques are being extensively used, patient-specific QA has become more critical. Various QA tools for IMRT are being studied. Low et al. [21] have provided a comprehensive overview of the optimal way with which dosimeters, phantoms, and dose distribution analysis techniques should be used to support commissioning and QA requirements in patient-specific QA.

In previous studies, IMRT and VMAT were verified using EPIDs and gamma analysis for patient-specific QA [23-26,28,29]. Mobius3D provides a second-check dosimetry system for the verification of the radiation treatment plan using a collapsed CC algorithm, besides the primary TPS. Unlike the conventional QA method, this system conducts patient-specific QA without a phantom setup, using the log files generated after treatment and CC algorithms.

Jung et al. [23] investigated the clinical performance of the online dosimetry system on 18 patients scheduled to undergo VMAT plans for head and neck, lung, and prostate cases. Dosimetric plan verification was performed using the gamma passing rates. The dose–volume metrics and error detection capability were evaluated by deliberately introducing machine error. The authors concluded that the log file-based online dosimetry system was a suitable verification tool for accurate and efficient clinical routine use in patient-specific QA.

Furthermore, Lee et al. [24] evaluated the dosimetric performance of Mobius3D by comparing this system with EPID and Octavius 4D, which are conventionally used for patient-specific prescription dose verification, in nine patients treated using VMAT. The authors showed the percentage differences between the calculated point dose and the measurements in a PTW31010 ionization chamber. These differences were 1.6%±1.3%, 2.0%±0.8%, and 1.2%±1.2% for the CC algorithm, AAA, and the AcurosXB algorithm, respectively. It was also reported that Mobius3D could be used interchangeably with the phantom-based dosimetry system that was commonly used for patient-specific QA with a 3%/3-mm and 95% passing rate.

Finally, McDonald et al. [25] compared the doses calculated using the AcurosXB algorithm of a primary TPS and Mobius3D and the dose measured in the A1SL ionization chamber for 36 intensity-modulated cases. The mean dose difference between Mobius and the measurement was 0.3%±1.3%, whereas the difference between AcurosXB and the measurement was −1.2%±0.7%. Mobius was consistent with the measurements in 3.5% of the cases. In addition, the accuracy of dose calculation and the independence of the Mobius system provided a rigorous secondary check of modern TPS.

Given these early reports, we aimed to investigate the

clinical performance of Mobius3D. Therefore, we performed the commissioning procedure recommended by the manufacturer and subsequently evaluated 122 cases of patients who underwent complex radiotherapy techniques.

Conclusions

We analyzed the patient-specific QA results of 122 patients who received radiation therapy using IMRT and VMAT on the Novalis Tx and VitalBeam linear accelerators. Portal dosimetry with an EPID, which is extensively used in clinical practice, and the newly released Mobius3D, which uses log files, were compared. The obtained results indicated that the patient-specific QA method using log files can be appropriately used in clinical practice as a second-check dosimetry system. This method is considered comparable with primary QA such as portal dosimetry.

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Conflicts of Interest

The authors have nothing to disclose.

Availability of Data and Materials

All relevant data are within the paper and its Supporting Information files.

Author Contributions

Conceptualization: Sung Yeop Kim and Se An Oh. Data curation and formal analysis: Sung Yeop Kim and Se An Oh. Funding acquisition: Se An Oh. Investigation: Sung Yeop Kim. Methodology: Sung Yeop Kim, Jaehyeon Park, Jae Won Park, Ji Woon Yea, and Se An Oh. Supervision: Se An Oh. Validation: Sung Yeop Kim, Jaehyeon Park, Jae Won Park, Ji Woon Yea, and Se An Oh. Writing–original draft: Sung Yeop Kim. Writing–review & editing: Sung Yeop Kim, Jaehyeon Park, Jae Won Park, Ji Woon Yea, and Se An Oh.

Ethics Approval and Consent to Participate

This study was approved by the Institutional Review Board of the Yeungnam University Medical Center (YUMC 2021-01-003). The need for informed consent was waived under the Institutional Review Board's approval, provided patient anonymity was ensured. All procedures were performed in accordance with the relevant guidelines and regulations.

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