Original Article

Prediction model for intraoperative implant volume using the 3D surface imaging system (VECTRA XT 3D) in direct-to-implant breast reconstructions

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Background: In direct-to-implant breast reconstruction, accurate preoperative breast volume estimation is crucial for surgeons to select the appropriate implant volume, considering the cosmetic outcomes during surgery. We proposed the prediction model for intraoperative implant volume based on the preoperative estimated volume of the contralateral breast obtained through a three-dimensional surface imaging system (3DSI) as surgeons usually choose the implant volume on the breast which should be reconstructed considering symmetricity with the contralateral breast.

Methods: We enrolled 97 patients from our single institution who underwent unilateral mastectomy with immediate breast reconstruction using smooth silicone implants between October 2021 and January 2023. Preoperatively, plastic surgeons measured the volume of the contralateral breast using the VECTRA XT 3D imaging system. Data on implant volume and the types of acellular dermal matrix used during surgery, determined by a single surgeon to ensure symmetry, were also collected. Linear regression analysis was utilized to construct the predictive model.

Results: In the multiple linear regression analysis with preoperative contralateral breast volume, age, and body mass index as variables, the coefficient of determination of the model expressed as R squared (R^2) was 0.554, and except for age, the other variables were statistically significant. When replaced by mastectomy volume instead of age, R^2 increased to 0.723 and all variables were significant.

Conclusions: 3DSI can be helpful for preoperative surgical planning and postoperative outcome simulation. With our multiple linear regression model, we can predict the intraoperative implant volume using preoperative contralateral breast volume measured by the 3D scans.

Keywords: Breast reconstruction; breast implant; three-dimensional imaging (3D imaging)

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Introduction

Breast reconstruction forms a vital and routine component in the surgical treatment of patients diagnosed with breast cancer (1). Especially in direct-to-implant breast reconstructions, estimating preoperative breast volume is crucial for surgical planning, enabling surgeons to select appropriately sized implants. This choice directly impacts the aesthetic outcomes and patient satisfaction following mastectomy (2).

In the past two decades, the application of three-dimensional surface imaging system (3DSI) has become increasingly prevalent in the field of plastic surgery. Initially introduced by Burke and Beard in 1967 for analyzing facial structures, 3DSI has now found significant usage in aesthetic breast surgery, primarily as an effective, non-invasive method for estimating breast volume (3,4). One of the key advantages of 3DSI lies in its ability to quantitatively analyze volume and shape differences that are not discernible through traditional two-dimensional imaging or physical examination (5). Additionally, 3DSI enables patients to view their own 3D images, providing them with a clearer understanding of the potential outcomes. For plastic surgeons, this technology serves as a valuable tool, allowing them to manipulate these images to simulate expected results post-breast reconstruction. This is particularly crucial for achieving symmetry in breast shape, especially on the side opposite the reconstruction site, which is a critical factor in determining the success of the surgical outcome (6).

Recent advancements in plastic surgery have seen the introduction of various 3DSIs, as documented in contemporary literature. These include the 3dMD system (3dMD LLC, Atlanta, GA, USA), Axis Three 3D Imaging system (AX3 Technologies LLC, Miami, FL, USA), Crisalix 3D Surface Imager (Crisalix, S.A., Lausanne, Switzerland), Dimensional Imaging DI3D (Direct Dimensions Inc., Owings Mills, MD, USA), and the Vectra XT 3D (Canfield Scientific, Parsippany, NJ, USA) (7). Among these, the Vectra XT 3D system is notable for its multiple cameras capturing images simultaneously from various angles with a rapid capture time of 3.5 milliseconds. The comprehensive visualization provided by this system is essential for both surgical planning and patient consultations (8).

In the realm of breast surgery, 3DSI was initially employed in the context of breast augmentation procedures. One study utilizing the VECTRA M3 imaging system for breast augmentation demonstrated the system's precision in pre-surgical simulations, revealing accuracies of 90% and 98.4% for volume and contour predictions, respectively, when compared to post-operative outcomes (9). In another study, the Crisalix 3D Surface Imager was used to compare the actual mastectomy volume with image estimates and anthropomorphic estimates based on the surgeon's experience and physical examination. The findings indicated that when the actual mastectomy volume was less than 600 cc, the predicted value from the 3DSI closely matched the actual mastectomy volume (10).

However, most existing research has focused on aesthetic procedures (11), with fewer studies exploring 3DSI for predicting implant volume in breast reconstruction. Through this study, we propose the analysis model to predict the intraoperative implant size through preoperative estimated volume of contralateral breast by VECTRA XT 3D and other patient factors as surgeons usually choose the implant size on the breast which should be reconstructed considering symmetricity with contralateral breast. We present this article in accordance with the TRIPOD reporting checklist (available at https://gs.amegroups.com/article/view/10.21037/gs-24-148/rc).

Highlight box

Key findings

- In determining the volume of breast implants to be inserted during direct-to-implant based breast reconstruction, a predictive model utilizing body mass index (BMI), mastectomy volume, and three-dimensional surface imaging system (3DSI) measurements of the unaffected breast demonstrated the highest explanatory power.

What is known and what is new?

- In breast cancer patients undergoing breast reconstruction, the selection of an appropriate breast implant size is crucial for achieving symmetry of breast shape and favorable aesthetic outcomes.
- It was demonstrated that by utilizing factors such as volume of the unaffected breast by 3DSI, age, BMI, mastectomy volume, and other relevant variables preoperatively, surgeons can select the appropriate type of breast implant to be inserted during surgery.

What is the implication, and what should change now?

- Other plastic surgeons can actively apply predictive models based on 3DSI to their respective patient populations, enabling them to provide sufficient explanation to patients and achieve favorable aesthetic outcomes.

Methods

The study was conducted in accordance with the

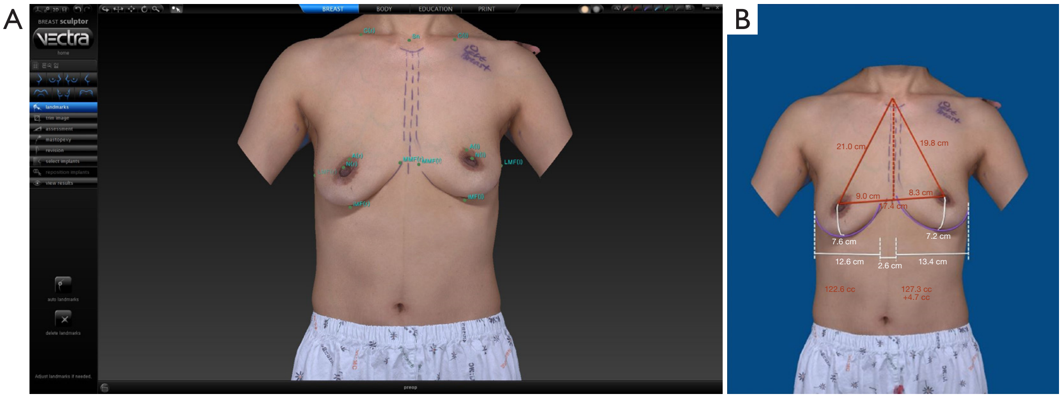

Figure 1 VECTRA XT 3D scanning method. (A) The boundaries and landmarks of the breast were first determined using automatic image analysis of the system, and if there was an error in specifying the area, the surgeon modified it manually. (B) VECTRA XT 3D image of a 45-year-old female patient whose preoperative contralateral breast volume is 122.6 cc.

Declaration of Helsinki (as revised in 2013). Ethical approval was granted by the Institutional Review Board of Yeungnam University Hospital (IRB No. 2023-06-032) and individual consent for this retrospective analysis was waived. Yeungnam University Hospital is a training hospital of Yeungnam University College of Medicine. Clinical practice and surgeries are conducted at Yeungnam University Hospital. Patients at our single institution who underwent unilateral mastectomy with immediate breast reconstruction with smooth silicone implant between October 2021 and January 2023 were enrolled. Mastectomies were performed by 3 breast surgeons at our single institution and all patients were at least 18 years old. Patients with breast ptosis grades 2 and 3 proposed by Regnault were excluded (12). Additionally, the study excluded patients who had undergone radiation therapy, bilateral breast reconstructions, and other types of aesthetic breast surgeries. A total of 97 patients (97 breasts) were included in the current study with a mean age of 47 years (range, 27–64 years).

Preoperatively, all patients were scanned using VECTRA XT 3D (Canfield Scientific) by plastic surgeons. At the moment of scanning, the patients stood in front of the machine and kept their arms open at 30 degrees. The boundaries and landmarks of the breast were first determined using automatic image analysis of the system, and if there was an error in specifying the area, the surgeon modified it manually (*Figure 1*).

In our study, we collected fundamental patient characteristics, including age, body mass index (BMI), underlying diseases, cancer stage, and history of chemotherapy treatments. We also collected the data on implant sizes and acellular dermal matrix (ADM) actually used intraoperatively by the same surgeon (J.H.L.) which was determined by considering the symmetricity with contralateral breast and aesthetic aspects that were visually identified by sitting the patient during the surgery. The implants [Sebbin (France), Mentor (USA), Eurosilicone (France)] wrapped by total wrapping method were set in prepectoral plane and the volume of ADM was calculated using the thickness and area of ADM by calculating the volume of the cuboid (13). The thickness and area of ADM were different by product name (Megaderm, CGderm, Myderm).

Statistical analysis

Through the simple and multiple linear regression analysis, we could predict the total volume of implant and ADM which will be used intraoperatively by estimating the volume of contralateral breast by VECTRA XT 3D. In addition, we also found that several patient factors influenced the accuracy of analyses model. Statistical analyses were performed using Microsoft Excel (Microsoft, Redmond, WA, USA) and SPSS (IBM, Armonk, NY, USA). A P value less than 0.05 was considered statistically significant.

Results

The demographics of the patients are shown in *Table 1*. The preoperative contralateral breast volume measured by VECTRA XT 3D is a variable which is continuous, we used

Table 1 Patients demographics

Variable	N (%)/mean (range)
Age, years	47 (27–64)
Body mass index, kg/m^2	22.69 (16.16–32.01)
Stage	
Lobular carcinoma *in situ*	1 (1.03)
Ductal carcinoma *in situ*	24 (24.74)
I	37 (38.14)
II	26 (26.80)
III	9 (9.28)
Underlying disease	
Hypertension	7 (7.22)
Diabetes mellitus	1 (1.03)
Hypothyroidism	6 (6.19)
Dyslipidemia	11 (11.34)
Chemotherapy (neoadjuvant)	12 (12.37)

Table 2 The simple linear regression model of the intraoperative breast volume actually used by plastic surgeon ('Implant Volume') on preoperative contralateral breast volume by VECTRA ('Preop-Contra')

Variable	Coefficient	SE	95% CI	P value
Preop-Contra, cc	0.500	0.056	86.545–148.081	<0.001*

*, P<0.05. B (constant) =117.426; adjusted R^2=0.456 (coefficient of determination). SE, standard error; CI, confidence interval.

simple linear regression analysis to predict the intraoperative breast volume composed of volume of the breast implant and ADM which will be actually used by the plastic surgeon. *Table 2* shows the relationship between preoperative contralateral breast volume by VECTRA (referred to as 'Preop-Contra') and intraoperative breast volume actually used by the plastic surgeon (referred to as 'Implant Volume'). The relationship between the two variables appears to be roughly linear, positive and statistically significant (P<0.001). The linear relationship is represented as follows (Model 1):

$$y(\text{Implant Volume}) = \beta_0(\text{constant}) + \beta_1(\text{the coefficient of Preop-Contra})\,x_1(\text{Preop-Contra}) \quad [1]$$

Other variables which potentially exert a confounding effect on the predicted value not only 'Preop-Contra' were considered suggesting the multiple linear regression analysis model through this study. By adding the factors including age and BMI, although the coefficient of the 'Preop-Contra' has decreased, the explanatory power of the statistical model which was expressed R squared (R^2) has increased from 0.456 to 0.554. 'Preop-Contra' and BMI were considered statistically significant factors of which P values were <0.001 and 0.001, respectively (*Table 3*). The linear relationships are represented as follows (Model 2):

$$y(\text{Implant Volume}) = \beta_0(\text{constant}) + \beta_1(\text{the coefficient of Preop-Contra})\,x_1(\text{Preop-Contra}) + \beta_2(\text{the coefficient of Age})\,x_2 + \beta_3(\text{the coefficient of BMI})\,x_3 \quad [2]$$

When replaced by mastectomy volume instead of age, R^2 increased to 0.723 and all variables were significant (*Table 4*). The linear relationships are represented as follows (Model 3):

Table 3 The multiple linear regression model of the intraoperative breast volume actually used by plastic surgeon ('Implant Volume') on preoperative contralateral breast volume by VECTRA ('Preop-Contra'), age and BMI

Variable	Coefficient	SE	95% CI	P value
Preop-Contra, cc	0.386	0.065	0.256 to 0.515	<0.001*
Age, years	−0.399	0.888	−2.170 to 1.372	0.65
BMI, kg/m^2	8.868	2.493	3.897 to −13.839	0.001*

*, P<0.05. B (constant) =−34.285; adjusted R^2=0.554 (coefficient of determination). SE, standard error; CI, confidence interval; BMI, body mass index.

Table 4 The multiple linear regression model of the intraoperative breast volume actually used by plastic surgeon ('Implant Volume') on preoperative contralateral breast volume by VECTRA ('Preop-Contra'), mastectomy volume and BMI

Variable	Coefficient	SE	95% CI	P value
Preop-Contra, cc	0.203	0.054	0.096 to 0.310	<0.001*
Mastectomy volume, cc	0.424	0.054	0.315 to 0.532	<0.001*
BMI, kg/m^2	4.227	1.840	0.572 to 7.882	0.02*

*, P<0.05. B (constant) =−3.734; adjusted R^2=0.723 (coefficient of determination). SE, standard error; CI, confidence interval; BMI, body mass index.

Table 5 The multiple linear regression model of the intraoperative breast volume actually used by plastic surgeon ('Implant Volume') on preoperative contralateral breast volume by VECTRA ('Preop-Contra'), mastectomy volume, contralateral breast width and BMI

Variable	Coefficient	SE	95% CI	P value
Preop-Contra, cc	0.197	0.058	0.082 to 0.313	0.001*
Mastectomy volume, cc	0.425	0.055	0.316 to 0.534	<0.001*
Contralateral breast width, cm	1.156	4.334	−7.454 to 9.765	0.79
BMI, kg/m^2	4.053	1.960	0.159 to 7.948	0.04*

*, P<0.05. B (constant) =−15.492; adjusted R^2=0.721 (coefficient of determination). SE, standard error; CI, confidence interval; BMI, body mass index.

$$\begin{aligned} y(\text{Implant Volume}) = {} & \beta_0(\text{constant}) + \beta_1(\text{the coefficient of Preop-Contra})x_1(\text{Preop-Contra}) + \\ & \beta_2(\text{the coefficient of Mastectomy volume})x_2 + \beta_3(\text{the coefficient of BMI})x_3 \end{aligned} \quad [3]$$

When the contralateral breast width (medial mammary fold to lateral mammary fold distance, cm) measured by 3DSI was added to Model 3, the R^2 slightly decreased to 0.721. While the P values for the other factors remained below 0.05, the P value for contralateral breast width was 0.79 (*Table 5*). The linear relationships are represented as follows (Model 4).

$$\begin{aligned} y(\text{Implant Volume}) = {} & \beta_0(\text{constant}) + \beta_1(\text{the coefficient of Preop-Contra})x_1(\text{Preop-Contra}) + \\ & \beta_2(\text{the coefficient of Mastectomy volume})x_2 + \beta_3(\text{the coefficient of Contralateral breast width})x_3 + \\ & \beta_4(\text{the coefficient of BMI})x_4 \end{aligned} \quad [4]$$

Discussion

In the process of preoperative planning for breast surgeries, numerous techniques have been employed to accurately determine breast volume. Among these is the water displacement method for mastectomy specimens, often referred to as the Archimedes procedure. This technique involves immersing the mastectomy specimen in a container of water, with the volume calculated based on the displaced water. Initially introduced by Bouman, this method was further refined by Tezel *et al.* (14). However, its intraoperative application limits the time available for surgeons to select appropriate breast implants and ADM types and volumes. The Grossman-Roudner device is another tool used in volume measurement. It comprises three cone-shaped plastic discs, measuring 16, 18, and 20 cm, suitable for measuring volumes ranging from 150–200, 200–300, to 300–425 mL, respectively. This method requires the patient to be seated with their arms at their sides for accurate measurement (15). Casting techniques using materials like gypsum, paraffin, and thermoplastics involve creating a mold of the chest, which is then filled with water or sand to measure volume (16). Advanced imaging techniques such as magnetic resonance imaging (MRI), computed tomography (CT), mammography, and ultrasound are also reliable, non-invasive methods for breast volume assessment. Recently, 3D models have been suggested for breast volume calculation using either laser scanning or stereo cameras. These models construct a 3D image, and after selecting the breast landmarks, the volume is calculated using simulation software (17,18).

One study in the field of implant-based breast reconstruction involved 59 breasts. Prior to surgery, the weight of each breast was measured using 3DSI. This single variable was then utilized to conduct a regression analysis to predict the weight of the mastectomy and the size of the implant during surgery (19). Another study with 56 patients used 3D volume of the healthy breast to establish a prediction model, which demonstrated higher explanatory power (20).

In this retrospective study, we used the Vectra XT 3D system (Canfield Scientific) to predict the intraoperative breast volume needed for implant and ADM substitution post-mastectomy, considering symmetry and aesthetic outcomes. By calculating ADM volume as a cuboid, we could suggest various combinations of implants and ADM based on predicted intraoperative volumes. In multiple regression analysis, many variables can result in a compound effect on the prediction of outcomes. In this model, a higher coefficient for one variable indicates that it has much more effects on the prediction of outcomes than the others. We predicted the intraoperative volume using *Table 3* and Model 2 before mastectomy. After mastectomy, a sizer is often used to determine the size and type of the implant. *Table 4* and Model 3 predicted the sizer volume based on the mastectomy volume, aiding inexperienced surgeons in selecting the appropriate sizer. This approach also provides guidance for surgeons who do not use sizers, assisting in the selection of suitable implants and ADM types during surgery. When breast width, a factor potentially influencing postoperative symmetry, was added to *Table 5* and Model 4, the explanatory power slightly decreased compared to *Table 4* and Model 3 without breast width. It was found that the P value for breast width was 0.79, suggesting that it is not an important consideration in the statistical analysis model for predicting implant size in this study.

In a 42-year-old female patient, the contralateral breast volume measured by VECTRA XT 3D before surgery was 145.7 cc, with a BMI of 18 kg/m^2, and the mastectomy volume was 139 cc. According to *Table 3* and Model 2, the estimated volume to be filled during surgery was 164.82 cc, while *Table 4* and Model 3 predicted 160.87 cc. Considering visual symmetry during the surgery, the chosen breast implant and ADM's combined volume was 160.5 cc, which closely matched the prediction from *Table 4* and Model 3. Thirteen months after the surgery, it was observed that both breasts were relatively symmetrical (*Figure 2*).

The difference from previous studies is that we investigated a larger number of variables prior to surgery, and proposed the use of different predictive models depending on the circumstances before and during surgery. Hence, when providing preoperative explanations to patients regarding the surgical procedure, a relatively concise and straightforward description can be offered regarding the approximate implant size to be inserted during surgery using 3DSI, which requires minimal time. From the surgeon's standpoint, it is feasible to prepare implants that can be considered for insertion during surgery prior to the procedure.

There are some limitations in our study. First, the patients with breast ptosis grades 2 and 3 proposed by Regnault *et al.* were excluded (12). In the 3DSI, there were some landmarks including medial or lateral mammary fold, sternal notch, midclavicular line, nipples, areolar margins and inframammary folds. When ptosis is in high grade, the inframammary folds are not easily detected by the system and it was also difficult to adjust the landmarks manually. Second, the mastectomy was done by three different general surgeon and thereby, amounts of breast volume consisting of breast parenchyma and skin flaps can be diverse. As preoperative contralateral breast volume by 3D imaging

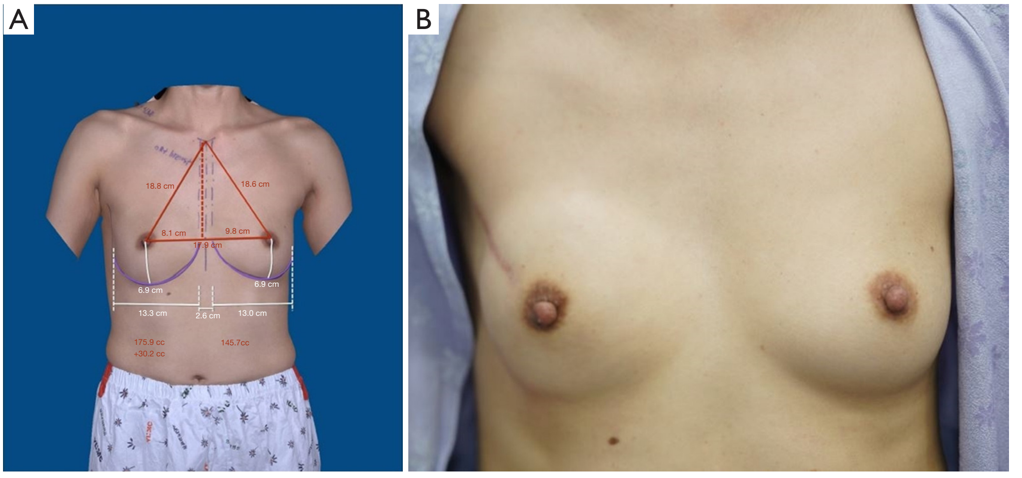

Figure 2 Breast implant selection using a prediction model and postoperative results. (A) In a 42-year-old female patient, the contralateral breast volume measured by VECTRA XT 3D before surgery was 145.7 cc, with a body mass index of 18 kg/m^2, and the mastectomy volume was 139 cc. (B) The breast volume required during direct-to-implant breast reconstruction was calculated using Model 2 before surgery, yielding a figure of 164.82 cc. After determining the mastectomy volume during the operation, Model 3 was used to calculate a volume of 160.87 cc. These measurements were referenced to combine an implant and acellular dermal matrix to achieve a fill of 160.5 cc. Thirteen months after the surgery, this approach resulted in relatively good symmetry.

system includes skin envelopes and breast parenchyma, the thickness of skin and the diversity of excised breast parenchyma can have an effect on the accuracy and reliability of prediction model. Therefore, preoperative measurement of the base diameter of the breast may serve as a more accurate factor in predicting implant size, indicating the need for further research in this area. Third, the actual volume of the ADM may differ from our calculated value, as we based our volume calculation on the assumption that ADM is a cuboid. Furthermore, according to a long-term study, it has been noted that the thickness of the ADM decreases by approximately 40% after being inserted into the body. While other factors such as density, area, etc., should be considered in volume measurement, given the average volume of ADM inserted in our study was 53.21 cc, it can be roughly estimated that there will be an average decrease of 21.28 cc after approximately 5 years (21). Hence, this error could have an influence on the total volume of the breast implants and ADM which were used intraoperatively. Fourth, while various types of breast implants were inserted, the impact of each implant's projection on the aesthetic outcome was not considered. Even with the same volume, the outward appearance may vary depending on the projection. In some cases where the patient's contralateral breast is significantly larger, the patient may desire procedures such as breast reduction or mastopexy. Consequently, it is necessary to explain in advance that breast implants may not be inserted based on the size of the contralateral breast before surgery.

Conclusions

In recent years, 3DSI has been widely used in breast reconstruction with implants and ADM after mastectomy. This technology is effective for preoperative planning and postoperative outcome simulation. However, selecting the appropriate breast implants and ADM for optimal aesthetic results remains challenging for plastic surgeons. Through this study by linear regressive model, we can predict the intraoperative breast volume using patient factors, preoperative contralateral breast volumes by 3DSI and the mastectomy volume.

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Footnote

Reporting Checklist: The authors have completed the TRIPOD reporting checklist. Available at https://gs.amegroups.com/article/view/10.21037/gs-24-148/rc

Data Sharing Statement: Available at https://gs.amegroups.com/article/view/10.21037/gs-24-148/dss

Peer Review File: Available at https://gs.amegroups.com/article/view/10.21037/gs-24-148/prf

Conflicts of Interest: Both authors have completed the ICMJE uniform disclosure form (available at https://gs.amegroups.com/article/view/10.21037/gs-24-148/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board of Yeungnam University Hospital (IRB No. 2023-06-032) and individual consent for this retrospective analysis was waived.

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