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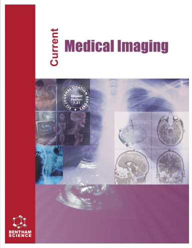

RESEARCH ARTICLE

Effect of Breath Training on Image Quality of Chest Magnetic Resonance Free-breathing Sequence

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Abstract:

Background:

Magnetic Resonance Imaging (MRI) plays a role in demonstrating substantial utility in lung lesion imaging, detection, diagnosis, and evaluation. Previous studies have found that free-breathing star VIBE sequences not only have high image quality but also have a high ability to detect and display nodules. However, in our routine clinical practice, we have encountered suboptimal image quality in the free-breathing sequences of certain patients.

Objective:

This study aims to assess the impact of breath training on the quality of chest magnetic resonance imaging obtained during free-breathing sequences.

Methods:

A total of 68 patients with lung lesions, such as nodules or masses detected *via* Computed Tomography (CT) examination, were prospectively gathered. They were then randomly divided into two groups: an observation group and a control group. Standard preparation was performed for all patients in both groups before the examination. The observation group underwent 30 minutes of breath training prior to the MRI examination additionally, followed by the acquisition of MRI free-breathing sequence images. The signal intensity (SI) and standard deviation (SD) of the lesion and adjacent normal lung tissue were measured, and the image signal-to-noise ratio (SNR) and contrast signal-to-noise ratio (CNR) of the lesion were calculated for objective image quality evaluation. The subjective image quality of the two groups of images was also evaluated using a 5-point method.

Results:

MRI examinations were completed in both groups. Significantly better subjective image quality (edge and internal structure clarity, vascular clarity, breathing and cardiac artifacts, and overall image quality) was achieved in the observation group compared to the control group ($P<0.05$). In addition, higher SNR and CNR values for disease lesions were observed in the observation group compared to the control group ($t=4.35$, $P<0.05$; $t=5.35$, $P<0.05$).

Conclusion:

It is concluded that the image quality of free-breathing sequences MRI can be improved through breath training before examination.

Keywords: Magnetic resonance, Lung, Image quality, Respiratory training, Signal, Intensity, Standard deviation.

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1. INTRODUCTION

Lung cancer ranks among the most prevalent and fatal cancers worldwide [1]. Early detection and treatment of lung cancer hinge upon the identification of pulmonary nodules, distinguishing between benign and malignant lesions, and assessing pathological subtypes. Computed Tomography (CT), along with artificial intelligence based on CT [2], serves as the predominant method for lung examinations. However, its application is discouraged for pregnant women, children, and patients requiring long-term follow-up [3]. Magnetic Resonance Imaging (MRI), an ionizing radiation-free and non-invasive technique, offers the capacity to evaluate lung morphology and function, demon-strating substantial utility in

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lung lesion imaging, detection, diagnosis, and evaluation [4 - 7].

In lung imaging scenarios, breath-holding represents an effective means of mitigating motion artifacts attributable to respiration [8]. Nevertheless, breath-holding imposes significant limitations on scan duration (typically 10 to 20 seconds in clinical settings), thereby constraining image quality, resolution, and coverage [9]. Breath-holding sequences necessitate patients to adhere to specific breathing instructions, which may pose challenges in routine clinical practice, particularly when dealing with pediatric or elderly patients with multiple comorbidities [9]. The navigation scheme requires patients to breathe regularly, but some patients breathe irregularly because of tension or pain, which leads to a decline in image quality and an increase in examination time [10]. Moreover, while it can be combined with rapid acquisition techniques like parallel acquisition, this may lead to diminished spatial image resolution [11].

The Free-breathing star 3D fat-suppressed T1-weighted gradient echo (star VIBE) builds upon the conventional VIBE sequence, and it is an optimized T1-weighted 3D gradient echo sequence featuring various fat-saturation options. Radial sampling is incorporated using a 3D 'stack-of-stars' approach, acquiring the kx-ky plane along radial spokes and the kz dimension with conventional sampling, thus achieving cylindrical k-space coverage [11 - 13], which reduces the pulmonary respiratory motion and the cardiac motion artifacts. Previous studies have found that freely breathing star VIBE sequences not only have high image quality but also have a high ability to detect and display nodules [6, 7]. Nonetheless, in our routine clinical practice, we have encountered suboptimal image quality in the free-breathing sequences of certain patients, which may be related to the breathing state of patients. At present, there are few reports about the image quality of pulmonary MRI free-breathing sequences. Yet, some studies studied the image quality improvement of abdominal diaphragm navigation in Magnetic Resonance Cholangiopancreatography (MRCP) and found that breath training can effectively improve the image quality of MRCP [14]. Therefore, the purpose of this study was to explore the value of breath training in the image quality of lung free breathing sequences and improve the image quality of the MRI free-breathing sequence.

2. MATERIALS AND METHODS

The institutional review committee granted approval for this study, and all patients provided written informed consent. We collected patients who underwent chest MRI examination in our hospital from June 2022 to June 2023. Inclusion criteria consisted of 1) Patients who underwent chest MRI and 2) the absence of MRI contraindications, which encompassed patients with pacemakers, artificial metal heart valves, individuals with ferromagnetic foreign bodies, patients in the first three months of pregnancy, patients with severe high fever and so on. Exclusion criteria included those who stopped the examination due to various reasons. Moreover, patients were matched based on age, sex, and lesion location and then randomly assigned to either the observation group or the control group. A total of 68 patients were enrolled, comprising 56 males and 12 females (Fig. **1**).

2.1. Image Acquisition

MRI studies were conducted utilizing a 3.0-Tesla MRI scanner (Skyra, Siemens, Germany) equipped with a phased-array multi-coil system comprising 16 elements. Images were acquired using star VIBE MRI sequences. The star VIBE sequence was acquired employing a completely free-breathing technique devoid of navigators or triggering methods. Star VIBE scanning parameters were as follows: Echo Time (TE): 1.39 ms; Repetition Time (TR): 2.79 ms; slice thickness: 1.25 mm; Field of View (FOV): 380 mm × 380 mm; matrix: 320 × 320; and scanning time: 330 seconds.

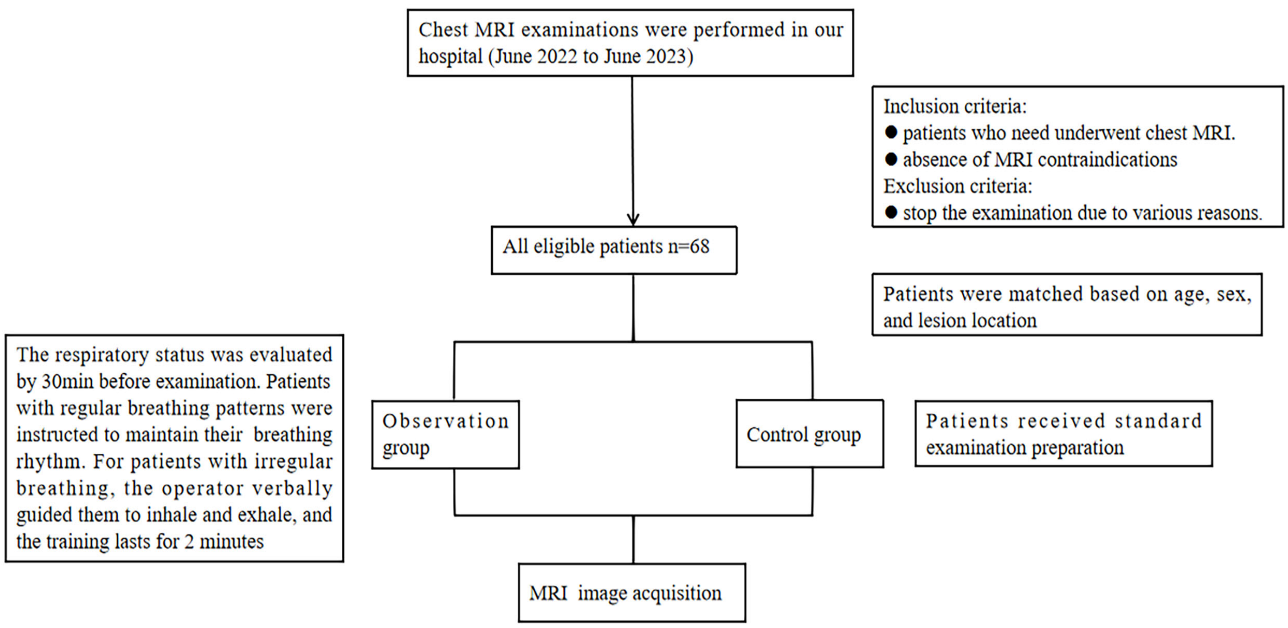

Fig. (1). The flowchart of the entire study.

2.2. Breath Training

Prior to the examination, the operator provided all patients with information regarding noise, heat sensations, examination duration, and other relevant considerations. The control group received standard examination preparation. The respiratory status of the patients in the observation group was evaluated 30 minutes before the examination. Patients with regular breathing patterns were instructed to maintain their natural breathing rhythm. For patients with irregular breathing, the operator verbally guided them to inhale and exhale, and the training lasted for 2 minutes. If irregular breathing persisted, the operator continued to provide guidance, extending the training time to 5 minutes.

2.3. Image Analysis

In a double-blind manner, two deputy chief physicians, each possessing over 10 years of MRI diagnostic experience, independently evaluated subjective image quality using a five-point scale. Subsequently, the average of their assessments was calculated as the final score. In cases of discordance between the assessments of the two physicians, a consensus was reached through discussion. The scoring encompassed edge and internal structure clarity, vascular clarity, breathing and cardiac motion artifacts, and overall image quality. Specific scoring criteria are detailed in Table **1**.

Star VIBE sequence images were transmitted to the post-processing workstation. Subsequently, the largest lesion slice and three consecutive slices were selected for measurement. Signal intensity (SI) was measured at each slice for both the lesions (SI_{lesion}) and adjacent normal lung tissue (SI_{tissue}). Sequentially, standard deviation (SD) was measured at each slice for both the lesions (SD_{lesion}) and adjacent normal lung tissue (SD_{tissue}). To ensure accuracy, the region of interest (ROI) for the lesion was carefully positioned to exclude potential non-solid areas, such as regions with bleeding or necrosis. Following this, the signal-to-noise ratio (SNR) and signal-to-noise ratio (CNR) of the lesions were calculated as follows: $SNR = SI_{lesion} / SD_{lesions}$, and $CNR = (SI_{lesions} - SI_{tissue}) / SD_{tissue}$.

2.4. Statistical Analysis

Statistical analyses were performed using SPSS software (version 26.0 SPSS, Chicago, IL, USA). All measurement data were presented as ($\bar{x} \pm s$). Normal distribution and variance homogeneity tests were conducted on each dataset. A paired sample t-test and Wilcoxon test were employed to compare the objective and subjective image quality between the control group and the observation group. Additionally, a Kappa test was administered by two radiologists to assess the consistency of subjective image evaluations.

3. RESULTS

3.1. Patient Characteristics

A total of 68 patients were enrolled, comprising 56 males and 12 females. The average age in the observation group was (71 ± 4.67) years, while in the control group, it was (64 ± 6.58) years.

3.2. Subjective Image Quality Evaluation

The agreement in subjective scoring of star VIBE images between the observation group and the control group was excellent (Kappa=0.88, 0.80; $P < 0.05$). Based on the assessments of the physician, the edge and internal structure clarity, vascular clarity, respiratory and cardiac artifacts, and overall image quality in the observation group surpassed that of the control group ($P < 0.05$) (Table **2**, Figs. **2** and **3**).

3.3. Objective Image Quality Evaluation

In terms of objective image quality evaluation, both the SNR and the CNR for disease lesions in the observation group significantly exceeded those in the control group (P<0.05), as presented in Table **3**.

Table 1. MRI subjective image quality scoring criteria for free breathing sequences.

-	1	2	3	4	5
Lesion edge and internal structure clarity	Non-diagnostic	Blurred	Slight clear	Clear	Very clear
Vascular clarity	Main trunk level	Lobar level	Segmental branch level	Sub-segmental branch level	Sub-sub-segmental branch level
Breathing and cardiac artifacts	Non-diagnostic	Severe artifact	Moderate artifacts	Slight artifacts	No artifact.
Overall image quality	Non-diagnostic	Poor	Acceptable	Good	Excellent

Table 2. Comparison of subjective image quality evaluation of MR images between the observation group and control group.

-	Observation Group	Control Group	*Z*	*P*
Lesion edge and internal structure clarity	4.35 ± 0.56	3.46 ± 0.76	3.90	<0.0001
Vascular clarity	4.04 ± 0.60	3.27 ± 0.72	3.60	<0.0001
Breathing and cardiac artifacts	3.92 ± 0.69	3.46 ± 0.81	2.56	0.011
Overall image quality	4.23 ± 0.43	3.42 ± 0.59	4.58	<0.0001

Table 3. Comparison of SNR and CNR values of MR images between the observation group and control group.

-	Observation Group	Control Group	*t*	*P*
SNR	24.92 ± 6.26	19.57 ± 4.00	4.35	<0.001
CNR	33.99 ± 8.86	25.41 ± 7.65	5.35	<0.001

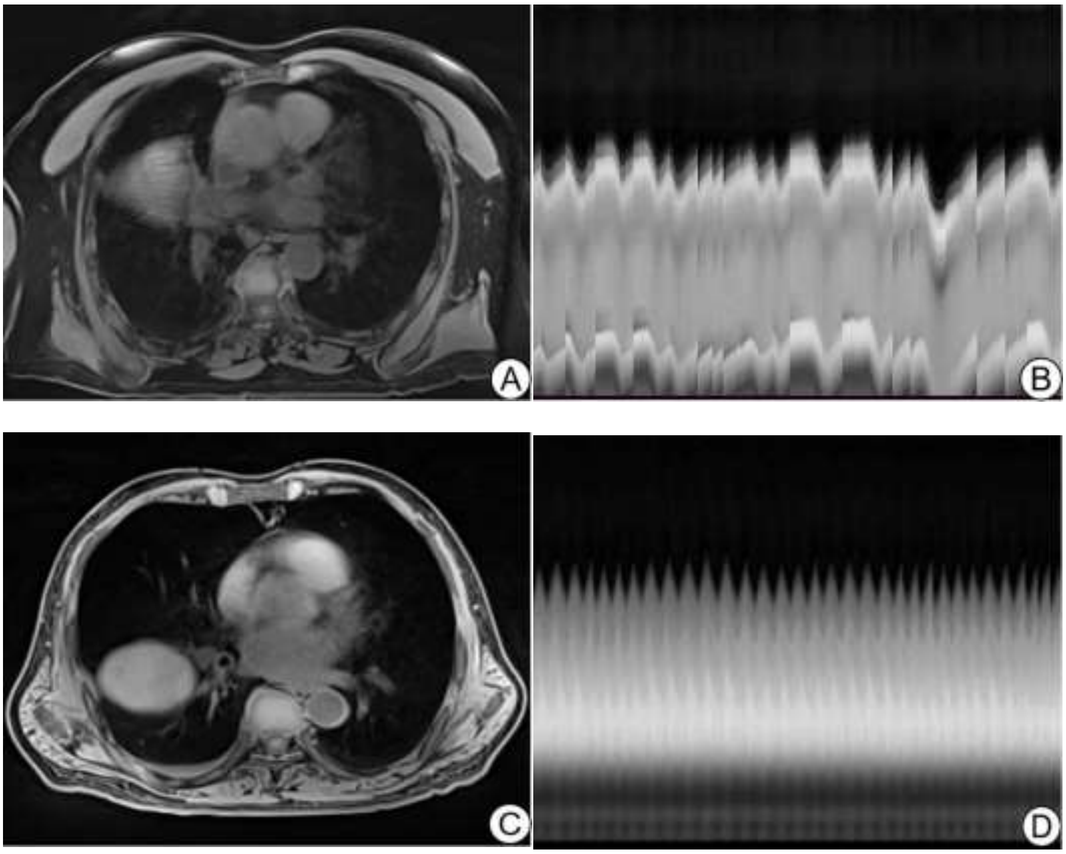

Fig. (2). A 69-year-old male who did not undergo breath training, irregular breathing (**B**), and MRI star VIBE image (**A**) showed substantial motion artifacts and indistinct lesion boundaries. In contrast, a 71-year-old man breathed regularly after breath training, and star VIBE images showed clear boundaries of the lesions (**C**, **D**).

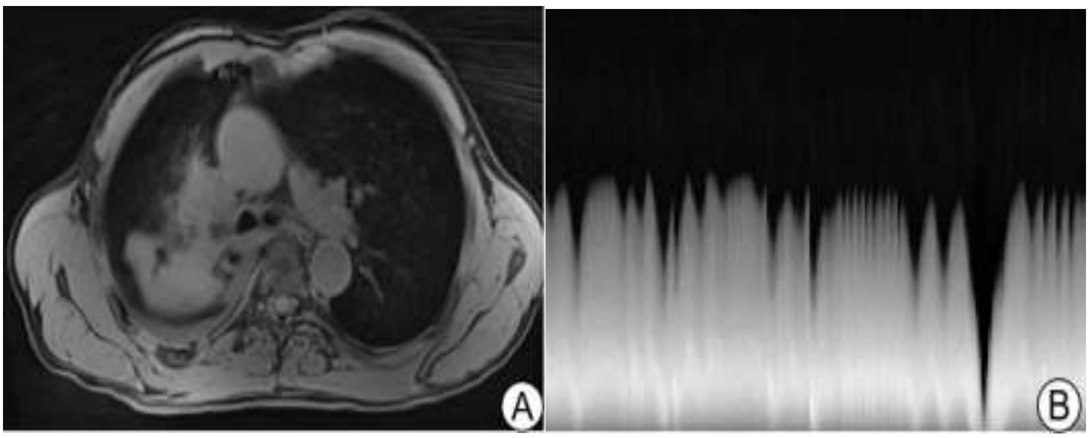

Fig. 3 contd.....

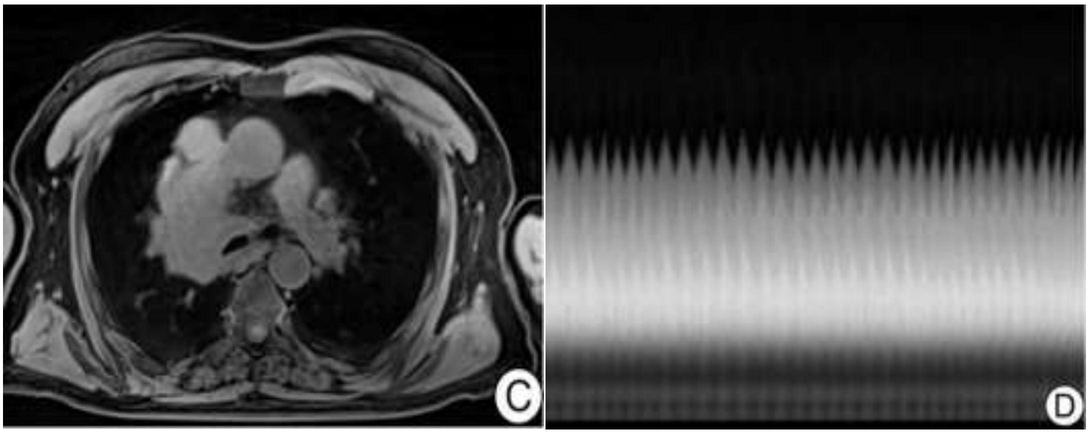

Fig. (3). A 75-year-old male who did not undergo breath training, irregular breathing (**B**), and the SNR of star VIBE was 18.76, and the CNR was 25.38 (A). In contrast, a 73-year-old man breathed regularly after breathing training, and the SNR of star VIBE was 21.54, and the CNR was 31.63 (**C**).

4. DISCUSSION

It was observed that conducting breath training prior to the examination has the potential to enhance lesion clarity and vascular clarity, reduce motion artifacts, and improve overall image quality. Besides, it can improve the SNR and CNR of magnetic resonance free-breathing sequence images.

In routine MRI procedures, we commonly employ three techniques, namely breath-holding sequences, free-breathing sequences, and navigation technology, to mitigate the impact of respiratory motion artifacts. Each of these methods comes with its own set of advantages and limitations. For individuals with robust lung function, breath-holding sequences yield superior image quality in a shorter time. Typically, conventional chest magnetic resonance employs breath-holding sequences; however, these sequences may not guarantee satisfactory image quality for patients who struggle with breath-holding or find it uncomfortable. On the other hand, navigation technology and free-breathing sequences do not necessitate patients to hold their breath during imaging. Respiratory navigation has demonstrated the potential to yield higher image quality [15], but it remains sensitive to variations in the respiratory frequency and amplitude of patients, leading to uncertainty in scanning times. Free-breathing sequences have fixed scanning times and are generally well-received by patients; however, the image quality of some patients is poor. Based on our clinical experience, we have identified that respiratory conditions in patients may impact image quality, leading us to propose the implementation of pre-examination breath training to enhance image quality.

Currently, the star VIBE sequence is a widely used chest free-breathing sequence [6, 16, 17]. A study by Yu *et al*. [16] compared the nodule detection capabilities and morphological sign display abilities of CT and star VIBE. They discovered that the overall nodule detection rate was 95%, with a 100% detection rate for nodules larger than 6mm. Furthermore, the star VIBE sequence exhibited good agreement with CT in terms of displaying lobulation, spinous processes, vascular convergence signs, cavities, vacuoles, and mediastinal lymph node enlargement. Scholars like Vermersch *et al*. [18] employed the free-breathing star VIBE sequence for staging lung cancer patients, noting that it provided superior image quality and diagnostic accuracy compared to traditional breath-holding VIBE sequences. Additionally, it improved patient comfort and enhanced assessments of lung nodules, lymph node involvement, and bone metastases performed by the doctors. In addition to capturing the morphological details of pulmonary nodules, it has been observed that dynamic contrast-enhanced MRI with the star VIBE sequence can mitigate issues related to poor breath holding due to contrast medium irritation. This approach enhances patient comfort and image resolution and provides more valuable information for clinically distinguishing between benign and malignant pulmonary nodules [19, 20]. Some researchers have also utilized free-breathing star VIBE sequences for liver puncture procedures, noting that this sequence facilitates better control over the positioning of the puncture needle and reduces the risk of needle dislodgment during the procedure [21].

Previous research has indicated improvements in the image quality of abdominal MRI breath-holding sequences by implementing adaptive breathing training for patients [22, 23]. Furthermore, some studies have highlighted enhanced imaging outcomes for MRCP navigated by the diaphragm through the application of breath training [14]. Consequently, the primary aim of this study was to investigate the potential value of breath training in enhancing the quality of free-breathing sequence images. Our findings affirm that breathing training can indeed elevate the quality of free-breathing sequence images. In our proposed method of breath training, we tailor the training to the respiratory pattern of the patient, enabling the patient to better control their own breathing rhythm during the examination. This approach ensures improved image quality, reduced motion artifacts, and a more comfortable experience for the patient during the examination.

5. LIMITATIONS

Several limitations should be acknowledged in this study. Firstly, the sample size was relatively small, underscoring the need for further research with larger sample sizes. Secondly, we did not assess the diagnostic accuracy of lung disease in patients who underwent respiratory training *versus* those who did not. Thirdly, despite our efforts to conduct randomized paired experiments based on age, sex, and lesion location, some variations in the experiments may have arisen due to individual differences.

CONCLUSION

In conclusion, pre-examination in breath training can enhance the image quality of lung free-breathing sequences and improve the overall examination comfort for patients. It is beneficial for the data collection of patients with poor respiratory coordination or irregular respiratory rhythm. In addition to lung MRI, we can also apply breath training to abdominal MRI examinations, such as liver, pancreas and kidney, which are easily affected by respiratory movements, so as to improve the image quality of abdominal MRI.

LIST OF ABBREVIATIONS

CT	=	Computed Tomography
MRI	=	Magnetic Resonance Imaging
star VIBE	=	star 3D fat-suppressed T1-weighted gradient echo
MRCP	=	Magnetic Resonance Cholangiopancreatography
TE	=	Echo Time
TR	=	Repetition Time
SNR	=	Signal-to-Noise Ratio
CNR	=	Contrast to-Noise Ratio
SI	=	Signal Intensity
SD	=	Standard Deviation
ROI	=	Region of Interest

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The present study was approved by the institutional review board of the affiliated hospital of Shaanxi University of Chinese Medicine, and all participating patients signed an informed consent. (Reference Number ?SZFYIEC-PJ-2019 [19]).

HUMAN AND ANIMAL RIGHTS

No animals were used for studies that are the basis of this research. All the humans were used in accordance with the ethical standards of the committee responsible for human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013 (http://ethics.iit.edu/ecodes/node/3931).

CONSENT FOR PUBLICATION

All patients provided written informed consent.

STANDARDS OF REPORTING

STROBE guidelines were followed.

AVAILABILITY OF DATA AND MATERIALS

The authors confirm that the data supporting the findings of this study are available from the corresponding author [N.Y] upon a reasonable request.

FUNDING

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Declared none.

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