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Delineation of intersegmental plane: application of blood flow blocking method in pulmonary segmentectomy

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Abstract

Background The Modified Inflation-Deflation Method (MIDM) is widely used in China in pulmonary segmentectomies. We optimized the procedure, which was named as Blood Flow Blocking Method (BFBM), also known as "No-Waiting Segmentectomy". This method has produced commendable clinical outcomes in segmentectomies. The aim of this research is to confirm whether the intersegmental planes formed by MIDM and BFBM techniques during segmentectomies have high degree of concordance.

Methods We utilized the Open Sequential Test design in our study. Using both MIDM and BFBM techniques, intersegmental planes were created in the same patient, one after the other. The degree of alignment between the planes formed by the two techniques was assessed by two experienced chief surgeons. Based on the results obtained in each case, a test line was plotted until it intersected the effective or ineffective line.

Results In every case studied, the intersegmental planes created by the MIDM and BFBM displayed high congruity. The test line crossed the effective line during the 12th case. When comparing the time taken to form the intersegmental plane using either MIDM or BFBM technique, no significant difference was observed. However, the application of the BFBM technique resulted in an average time savings of 13.8 min.

Conclusions In segmentectomies, the intersegmental planes formed by MIDM and BFBM techniques exhibit high concordance. However, given that BFBM affords a time-saving advantage, we propose that BFBM could potentially replace MIDM in performing lung segmentectomies.

Keywords Pulmonary segmentectomies, Intersegmental planes, Modified inflation-deflation method, Blood flow blocking method (BFBM)

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Introduction

Research conducted by Ginsberg, R. J. et al. in 1995 established pulmonary lobectomy as the standard surgical procedure for early-stage lung cancer [1]. However, with surgical advancements and the increased detection of early-stage lung cancer [2, 3], the predominance of lobectomy for peripheral early lung cancer has since been challenged [4–6]. Findings from the JCOG0802 study [7] suggest that segmentectomy is applicable not only for tumors with a consolidation-to-tumor ratio (CTR) ≤ 0.5, but also for those with a CTR > 0.5 in peripheral non-small cell lung cancer patients with tumors ≤ 2 cm. Furthermore, the oncological outcome is not inferior to that of lobectomy. Similarly, the CALGB 140,503 study [8] shows that for peripheral non-small cell lung cancer (cT1N0M0) ≤ 2 cm, the sub-lobectomy group demonstrated comparable Disease-Free Survival (DFS) and Overall Survival (OS) rates with the lobectomy group, and nearly half of the sub-lobectomies performed were segmentectomies. These results indicate that the acceptance of segmentectomy as a feasible approach in managing peripheral early non-small cell lung cancer is likely to increase. Significantly, segmentectomy is seen as more beneficial than wedge resection due to its lower local recurrence rate [9].

Pulmonary segmentectomy entails greater complexity than wedge resection or lobectomy, necessitating more precise anatomical understanding. A key step in pulmonary segmentectomy is the delineation of the intersegmental plane. Currently, there are various methods to identify the lung intersegmental plane, falling into two main categories: via the trachea [10–13] or through the blood vessels [14–18]. One trachea-based method involves injecting indocyanine green into the segmental bronchus [10], and staining the target segment. Conversely, a method utilizing blood vessels involves the peripheral intravenous injection of indocyanine green [18]. MIDM [15] is another blood vessel-based approach widely utilized in China, attributing its popularity to its efficacy and lack of requirement for any additional equipment. Building upon the MIDM, we further refined the BFBM, also known as "No-Waiting Segmentectomy", which has produced commendable clinical outcomes and time-saving advantages in segmentectomies [19]. However, the degree of concordance between the intersegmental planes formed by BFBM and MIDM remains uncertain. Subscribing to this paradigm, our prospective study was designed to investigate whether the intersegmental planes formed by MIDM and BFBM techniques during segmentectomies have high degree of concordance.

Methods

Study design: this study employs an open sequential test design

The intersegmental planes formed by BFBM and MIDM were evaluated by two other experienced chief thoracic surgeons and the results were categorized into two types: concordant or discordant. If the two intersegmental planes did not show significant visual deviation and would not result in noticeable differences in cutting boundaries, they were considered concordant; otherwise, they were deemed discordant. if the concordance rate exceeded 90%, the intersegmental planes established by the two methods were deemed to be highly congruent. Conversely, if the concordance rate fell below 70%, the intersegmental planes formed by these methods were not deemed to exhibit a high degree of congruence.

The value for type I error (α) is set at 0.05

Eligible patients are randomly selected one-by-one from hospitalized patients scheduled for surgery. The experiment is halted and statistical inferences are made once the test line touches either the effective or ineffective line on the nth patient.

This study also uses a self-control design. The comparison of average values is analyzed by the Paired-Samples T-test, with a p-value less than 0.05 considered statistically significant.

Patient selection

Inclusion criteria: no surgical contraindication, pulmonary metastatic tumor or benign nodule need segmentectomy or in line with segmental resection conditions from the NCCN guidelines for non-small cell lung cancer: poor pulmonary reserve (not caused by severe emphysema) or the other major comorbidity that contraindicates lobectomy; peripheral nodule ≤ 2 cm with at least one of the following: pure Adenocarcinoma in Situ (AIS) histology; nodule has ≥50% ground glass appearance on CT; radiologic surveillance confirms a long doubling time (≥400 days).

Exclusion criteria: those with severe emphysema indicated by CT

Termination criteria: severe pleural adhesions, operation changed to lobectomy or operative time exceeding 4 h.

The process of MIDM: During the process of lung segmentectomy, we first deflate the lung on the surgical side, then deal with the artery, vein, and bronchus of the target lung segment, then the collapsed lung had to be completely re-expanded using pure oxygen with the bronchus on the operation side left open to the atmosphere while continuous ventilation of the contralateral lung is maintained. Then we wait for the intersegmental plane to gradually form.

The process of BFBM: During the process of lung segmentectomy, we first deflate the lung on the surgical side, then we identify and ligate all the arteries of the target segment, at this point, the vein and bronchus of the target lung segment have not yet been severed, then we reinflate the lung on the surgical side using pure oxygen with the bronchus on the operation side left open to the atmosphere while continuous ventilation of the contralateral lung, the intersegmental plane will gradually form. However, for some lung segments, because the artery is located inside the lung while the vein is on the surface of the lung, we deal with the vein first, and these lung segments include: S9(lateral-basal segment), S10(posterior-basal segment), S^{9+10}(lateral-basal segment+posterior-basal segment) and S^{3} (anterior segment) on both sides. During the formation of the intersegmental plane, we can continue with surgical operations.

Operation: The procedure involves general anesthesia and the patient is positioned in a lateral decubitus position on the healthy side. Intubation is performed using a double-lumen tube and a uniportal thoracoscopic operation is performed via a 3–4 cm incision between the fourth or fifth rib, located between the front axillary line and the midaxillary line. A 3D reconstruction is created based on 1 mm chest CT images before the operation. During the surgical procedure, we identify and ligate all the arteries or veins of the target segment, after that we reinflate the lung on the surgical side using pure oxygen with the bronchus on the operation side left open to the atmosphere while continuous ventilation of the contralateral lung, we continue with the surgical operations to deal with the remaining vessels and segmental bronchus, once the intersegmental plane is formed, we use an electric scalpel to cauterize and mark it (Fig. 1).This first intersegmental plane is the one formed using the BFBM method. Once all arteries, veins, and bronchus of the targeted segments are identified and ligated, we expand the lung again and wait for the second intersegmental plane to form, the second intersegmental plane is the one formed using the MIDM method (Fig. 2). The two planes are then assessed by two other experienced chief thoracic surgeons.

This is a right lower lung S^{7+8} segmentectomy. The intersegmental plane on the diaphragmatic surface was formed for the first time using BFBM and marked with an electrotome.

The electrotome marks indicate the first-formed intersegmental plane, while the boundary between the dark and bright represents the intersegmental plane formed for the second time using MIDM.

Results

The study was concluded upon the enrollment of 12 patients, as by the 12th case, the test line had achieved the desired effect. The outcome in each instance was consistent, as depicted in Table 1.

U: effective line, L: ineffective line. Based on the results from each patient, the test line consistently progressed upwards and eventually reached the effective line in the 12th case.

Within the group of 12 patients, there were 5 males and 7 females with an average age of 50.8 years. 11 patients presented with ground glass opacities (GGOs), while one patient had a metastatic tumor. The average operative time spanned approximately 96.9 min. Postoperative decannulation of the thoracic drainage tube averaged 2 days, while the mean discharge time was 4.3 days. One patient had an extended hospital stay of 11 days due to a

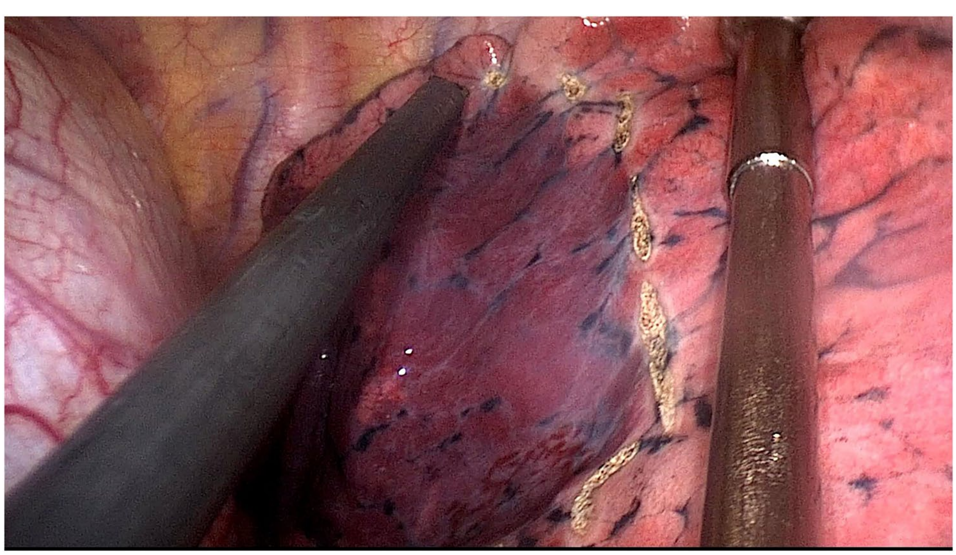
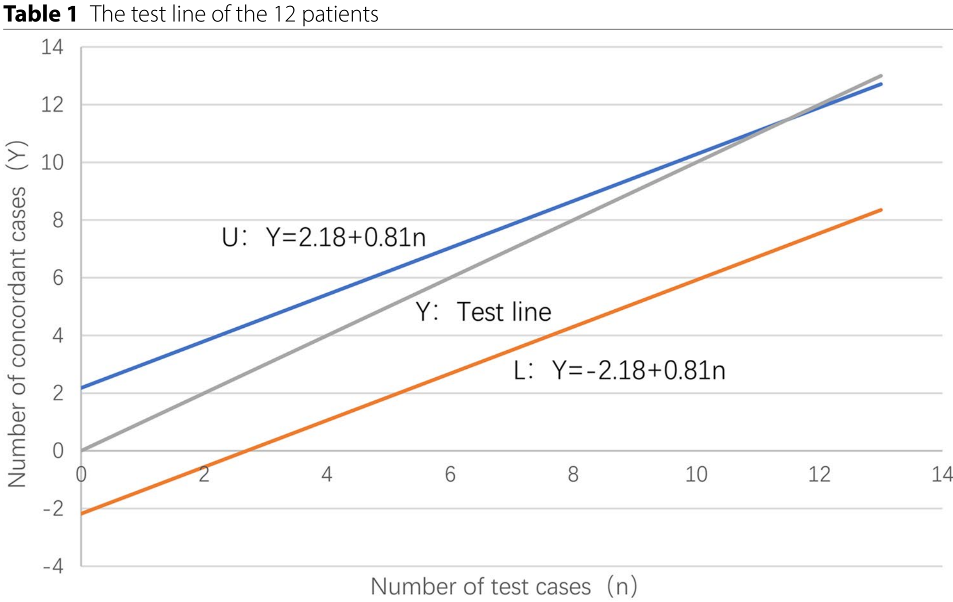


Fig. 1 Intersegmental plane formed by BFBM

Fig. 2 Intersegmental plane formed by MIDM

Table 1 The test line of the 12 patients



persistent low-grade fever post-operation (see Table 2 for details).

R: right, L: left, S^{7+8}: medial-basal segment+anterior-basal segment; S^{6}, superior segment; S^{8}: anterior-basal segment; S^{10}: posterior-basal segment; S^{9+10}: lateral-basal segment+posterior-basal segment; S^{4+5}: superior lingular segment+inferior lingular segment, S^{1+2+3}: apico-posterior segment+anterior segment; S^{2}: posterior segment; S^{3}: anterior segment; S^{9}: lateral-basal segment.

None of the patients experienced postoperative air leakage. The average time taken by BFBM to demonstrate the formed intersegmental plane was 13.9 min, while MIDM took an average of 13.8 min. The differences in these times were statistically insignificant ($p=0.857$).

Upon subtracting the MIDM time from the total operation duration, the resultant operation time attributed solely to BFBM usage was estimated to be 83.1 min on average. This means that using BFBM alone took 13.8 min less time compared to using MIDM, a difference that proved to be statistically significant ($p<0.001$) as shown in Table 3.

Discussion

The BFBM and MIDM processes have significant similarities, but the main difference is that the intersegmental plane can begin to form after the artery or vein of the target lung segment has been served when using BFBM. When using MIDM, all the arteries, veins, and bronchus

Table 2 Basic dates of the 12 patients

No	Age(yeas)	Sex	Segment	Operative time (mins)	Drainage time (days)	Discharge time (days)	Time of BFBM(mins)	Time of MIDM(mins)
1	58	F	RS^{7+8}	135	2	2	20	21
2	64	F	RS^{6}	69	1	3	9	12
3	48	F	LS^{8}	80	3	3	23	22
4	44	F	LS^{10}	141	4	5	15	15
5	45	F	RS^{9+10}	108	2	3	18	15
6	50	M	LS^{4+5}	61	3	2	9	8
7	54	F	LS^{1+2+3}	81	2	11	11	11
8	65	F	RS^{2}	80	2	7	15	16
9	39	M	RS^{6}	75	1	3	8	6
10	47	M	RS^{3}	115	1	4	8	8
11	57	M	LS^{9}	126	2	5	17	18
12	39	M	LS^{4+5}	92	1	4	14	14

Table 3 Difference between BFBM and MIDM

	BFBM	MIDM	*p*
Time for intersegmental plane (mins)	13.9	13.8	0.857
Operative time (mins) *	83.1	96.9	< 0.001

* The operation time attributed to BFBM was determined by subtracting the time taken for the formation of the intersegmental plane by MIDM from the total operation duration

should be served before inflating the lung to display the intersegmental plane. Before performing a lung segmentectomy, it is necessary to deflate the lung, but often we start the surgery before the lung is completely deflated. In some segmental lung surgeries, especially for the resection of segment S^6, there is often only one artery. When the interlobar fissure is well demonstrated, the artery can be quickly ligated. At this point, the lung has not yet been fully deflated. Continuing with the surgery, we unexpectedly found that a intersegmental plane began to form gradually without using the MIDM. Therefore, we realized that ligating the artery could form the intersegmental plane. Subsequently, we discovered that ligating all the veins of the target lung segment could achieve a similar effect. Thus, we named this method as BFBM.

The findings of this research demonstrate a high concordance between the intersegmental planes formed by BFBM and MIDM. The elapsed time required to expose these intersegmental planes using either method showed no significant difference. However, one notable advantage of using BFBM is that it saved an average of 13.8 min in operative time. This is because the operation could continue while waiting for the formation of the intersegmental plane when using BFBM, potentially speeding up patient recovery. Thus, considering these results, we propose that BFBM could effectively replace MIDM in the execution of segmentectomies.

In this study, we employed a self-control method to mitigate individual variances. But this design is not very accurate for comparing the surgical time of two methods, because during the process of waiting for the intersegmental plane using BFBM, the lung tissue is not fully collapsed at the beginning. At this point, continuing the surgical procedure to deal with the remaining segmental structures can be challenging. It is easier to operate when using MIDM, as the lung is fully collapsed when dealing with segmental structures. This may negate the advantage of saving surgical time for BFBM. Prior to conducting this study, we had conducted a retrospective study [19] comparing the differences between two groups of patients who underwent surgery using MDIM and BFBM (referred to as "No-waiting segmentectomy" in that paper). After performing Propensity Score Matching, the statistics showed that using BFBM (80.12±35.53 min) reduced surgical time compared to MIDM (102.97±48.07) in lung segmentectomy, with a significant difference (p=0.03). Based on this conclusion, we have adopted a relatively simple surgical time comparison strategy in this study, where the total surgical time is considered as the surgical time for using MIDM, and the time taken to form the intersegmental plane using MIDM is subtracted directly from the total surgical time to obtain the surgical time for BFBM. In actual surgical procedures, when the lung tissue is fully inflated and then ventilation is stopped while maintaining communication between the operative side lung and the atmosphere, the lung tissue rapidly collapses partially due to compliance. At this point, performing surgical procedures to dissect the segmental gate does not encounter significant interference. For patients with poor lung compliance, other essential and less interfering operations such as lymph node sampling can be prioritized. Therefore, continuing the surgical procedure during the waiting period for the intersegmental plane with BFBM does not result in significant time loss. Thus, we believe that the conclusion in this study regarding the reduction of surgical time with BFBM is reliable.

Despite the smaller sample size of just 12 patients, we were able to obtain satisfactory results using the Open Sequential Test. The 12 segmentectomies performed during the study included six cases from the right lung, six from the left lung; five from the upper lung, and seven from the lower lung. The operations comprised six simple segmentectomies (S^6, S^{4+5}, S^{1+2+3}, S^2), alongside six complex segmentectomies (S^{7+8}, S^8, S^{10}, S^{9+10}, S^3, S^9) [20], This encompassed a broad range of common segmentectomy types. The decision to limit the sample size was based on the fact that all cases yielded concordant results. In line with our study design, the research was concluded once the test line intersected with the effective line at the 12th case.

The identified improvement in surgical methods has the potential not only to save operation time, but also, more importantly, to simplify complex segmental resections that involve two or more borderlines with adjacent segments. By utilizing the BFBM approach, the intersegmental plane can be effectively formed approximately 13 min after ligating the arteries or veins of the targeted lung segment. Typically, this stage corresponds to approximately one-third of the entire surgical process. Dealing with the bronchus and remaining vessels in the segment hilum can prove challenging in complex segmentectomies due to limited exposure. However, with the intersegmental plane visible, one side of the plane can be prioritized, thereby enhancing the exposure of the segment hilum and potentially simplifying the surgical procedure. Our team had gained extensive experience in simplifying complex segmentectomies using this enhanced approach, and we intend to determine its effectiveness in forthcoming studies.

The BFBM method is reliant on blood vessels, making accurate recognition of these vessels essential for effectively obtaining intersegmental planes. Thus, 3D reconstruction should be performed prior to the surgery when using BFBM.

Apart from segmentectomy, we postulate that BFBM could potentially be employed in combined subsegmental resection, aligning with the underlying logic of BFBM coupled with our accrued experience. Additionally, BFBM might be suitable for lesion positioning in wedge resection. Generally, this involves ligating only one vessel, the drainage area of which contains the targeted lesion.

However, BFBM may not be suitable for all patients; specifically, those with severe emphysema and pleural adhesions. For these patients, the formation of the intersegmental plane may take a longer duration, which is always more than half an hour and the resultant plane may not be as distinct. In such scenarios, we favor the peripheral intravenous injection of indocyanine green [18]. However, this approach necessitates a fluorescent display, a resource that is unavailable in many county hospitals in China. Although patients with severe emphysema are not very suitable for this method, as it takes a long time to reveal the intersegmental plane and resultant plane is not very clear, we therefore excluded patients with emphysema from this study. However, in practical application, patients with emphysema are more suitable for BFBM compared to MIDM, because the BFBM method allows for continuous surgical manipulation during the waiting period for the intersegmental plane to appear, which can save more time compared to patients without severe emphysema.

Hong-Hao Fu [21] proposed the arterial-ligation-alone method. He conducted a retrospective study demonstrating a high level of concordance between the intersegmental planes formed by the arterial-ligation-alone method and the MIDM. In the artery-first severed segmentectomies, our method is exactly the same as his, However, we have extended this method to surgeries where veins are prioritized for treatment.

In 2013, Hisashi Iwata [17] introduced a surgical technique that demonstrated the formation of intersegmental planes. This method was later refined by Wang, J [15] evolving into what we now call the MIDM technique, which is widely employed in China. Iwata's methodology is based on the understanding that the arteries and veins of a lung segment facilitate the process of gas exchange. Ligation of these arteries and veins inhibits this gas exchange within the segment, thereby creating a plane between the segments that can and cannot facilitate gas exchange. In Iwata's original method, the first step is to ligate the segmental pulmonary arteries and veins. Following this, the entire lung lobe is inflated with pure oxygen. Then, the segmental bronchus is immediately stapled, and the medical team waits for the plane to appear. The MIDM procedure is similar, with one vital difference: the segmental bronchus is ligated before the lung is inflated. This change effectively represents the progression of this surgical technique from Iwata's original method to the improved MIDM. To validate Hisashi Iwata's theory, we performed an experiment wherein an isolated lobe was expanded using pure carbon dioxide gas. It was observed that the lung tissue turned dark red several minutes after excision from a patient requiring lobectomy due to lung cancer. However, after inflating the isolated lobe with pure carbon dioxide gas, the tissue turned pink. Upon deflation, the tissue returned to its dark red color. This experiment suggested that the color change in the lung tissue was not influenced by the nature of the gas but by the volume of air within the alveoli. Furthermore, we discovered that the formation of the intersegmental plane could occur regardless of whether or not the segmental bronchus was ligated. This finding suggests that the formation of the intersegmental plane depends on the blood circulation in the lung segment, which aids in gas exchange. Thus, an intersegmental plane can be formed by merely halting blood circulation in the pulmonary segments, i.e., by ligating either the arteries or veins in the pulmonary segments. This reasoning forms the basis of the BFBM method, indicating that BFBM, MIDM, and Iwata's approach share a common scientific rationale. Although they all operate under the same principle, our method enhances the process through procedural improvements.

Conclusions

Our study findings show a strong concordance between the intersegmental planes formed by BFBM and MIDM. However, using the BFBM method has been observed to have a shorter operative time compared to using MIDM. Hence, based on these results, we propose that BFBM could effectively replace MIDM in segmentectomies.

Abbreviations

MIDM	Modified Inflation-Deflation Method
BFBM	Blood Flow Blocking Method
CTR	Consolidation-to-tumor ratio
JCOG	Japan Clinical Oncology Group and the West Japan Oncology Group
CALGB	Cancer and Leukemia Group B
cT1N0M0	Clinical Tumor stage 1, Node stage 0, Metastases stage 0
DFS	Disease-Free Survival
OS	Overall Survival
NCCN	National Comprehensive Cancer Network
AIS	Adenocarcinoma in Situ
CT	Computed Tomography
GGO	Ground glass opacity
R	Right
L	Left
S^2	Posterior segment
S^3	Anterior segment
S^{1+2+3}	Apico-posterior segment + anterior segment
S^{4+5}	Superior lingular segment + inferior lingular segment
S^6	Superior segment
S^{7+8}	Medial-basal segment + anterior-basal segment
S^8	Anterior-basal segment
S^9	Lateral-basal segment
S^{9+10}	Lateral-basal segment + posterior-basal segment
S^{10}	Posterior-basal segment

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None.

Author contributions
The research proposal was proposed by Jian Zeng, Changchun Wang and Qixun Chen. The study design, surgery and writing of the paper were completed by Lei Cai. The two intersegmental planes were assessed by Jian Zeng, Changchun Wang and Qixun Chen. Anesthesia during the surgery was administered by Shuang Fu. Data analysis was carried out by Lei Cai and Taobo Luo. Chao Pan, Xiancong Huang, Jinxiao Liang, Yiding Feng, Wenkui Mo, and Haoting Xu managed the patients and collected the data. All authors reviewed the manuscript.

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Data availability
The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
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 approved by the ethics board of Zhejiang Cancer Hospital (IRB-2020-333) and informed consent was obtained from all patients.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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