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Case Report

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A Retrospective Comparative Study on The Clinical Application of Watershed Segmentectomy Versus Anatomical Segmentectomy in GGO-type Lung Adenocarcinoma

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Abstract

OBJECTIVE To compare watershed segmentectomy with anatomic segmentectomy in the clinical application of ground-glass opacity type lung cancer and to explore its prospects.

METHODS We retrospectively analyzed the clinicopathological features and perioperative parameters of 327 patients with ground-glass dominant (consolidation-to-tumor ratio ≤ 0.5) small tumors (whole tumor size ≤ 2 cm) and early stage non-small-cell lung cancer in the Department of Thoracic Surgery of The First Affiliated Hospital of Chongqing Medical University from September 2021 to March 2024. Among them, 181 and 146 patients underwent watershed segmentectomy and anatomic segmentectomy, respectively.

RESULTS Compared to anatomic segmentectomy, watershed segmentectomy had fewer lymph node dissections [(2 [1, 4]) vs. (4 [2, 6]), P<0.001], shorter surgical duration [(80 [60, 95]) min vs. (90 [80, 105]) min, P<0.001], less blood loss [(50 [50, 50]) ml vs. (100 [50, 100]) ml, P<0.001], and a lower postoperative complication rate (P<0.05). No positive results were observed in frozen sections of the lung margins in either group.

CONCLUSION Watershed segmentectomy can shorten surgical duration and reduce operative blood loss. It is a simple, safe, and effective procedure for patients with subsolid tumors located in the outer one-third of the lung field, which are ≤ 2 cm in size.

Key words Anatomical segmentectomy; watershed segmentectomy; Ground glass opacity; Perioperative period; Adenocarcinoma

INTRODUCTION

Lung cancer is the leading cause of cancer-related mortality and the second most common cancer worldwide (1). Several studies have confirmed the non-inferiority of 5-year survival after segmentectomy compared to lobectomy in peripheral tumors with a diameter ≤2.0 cm (2-5). Segmentectomy not only preserves pulmonary function but is also particularly beneficial for elderly patients with compromised lung function and is more suitable for treating multiple nodules (6, 7). Sublobar resection can also be an option for secondary pulmonary resection (8). When patients have multiple nodules, sublobar resection (including segmentectomy and wedge resection) can improve the postoperative quality of life by preserving pulmonary function to the greatest extent while adhering to oncologic principles (9). Moreover, preserved pulmonary function is inversely correlated with the number of resected lung segments (10). Segmentectomy is expected to become the standard procedure for peripheral nodular lung cancers measuring < 2 cm. However, because of the need to separate the hilar structures and identify and isolate the target segmental vessels and bronchi, anatomical segmentectomy is more challenging than a conventional lobectomy.

Our surgical team was the first to introduce the concept of watershed segmentectomy, function-preserving sublobectomy following extensive early clinical practice (11). A typical example is when a lung tumor is located on V2c. Using an approach via the fissure, the central vein can be dissected, and the plane defined by transecting V2c with the staplers, achieving optimal lung tissue preservation. Similarly, this principle applies to cases involving V1a, V1b, V6c, etc. The intersegmental plane can be identified by transecting only the artery or intersegmental vein. Unlike conventional anatomic segmentectomy, in which the intersegmental plane is delineated by transecting the bronchus for ventilation-guided demarcation, bronchus transection may be dispensable for resection of peripheral

tumors. In contrast, standard anatomic segmentectomy requires simultaneous division of the artery, vein, and bronchus. Accordingly, this study retrospectively analyzed clinical data from patients with early-stage lung cancer who underwent sublobar resection at our center. We aimed to compare perioperative outcomes between watershed segmentectomy (segmentectomy performed after dividing only the vessels within the tumor-draining territory) and anatomic segmentectomy and further explore the clinical utility of watershed segmentectomy.

Materials and methods

Patients Eligibility

This study retrospectively included patients who underwent thoracoscopic segmentectomy between September 2021 and March 2024 in the Department of Thoracic Surgery of The First Affiliated Hospital of Chongqing Medical University. The inclusion criteria were as follows: ① age 18-80 years. ② FEV1 ≥ 1.5 L and ≥ 60% predicted in the preoperative pulmonary function tests. ③ ground glass opacity (GGO) with a CTR ≤ 50%. 2 cm or smaller, pathological staging of stage ⅠA2 or earlier. ④ persistence, enlargement, or increased density of GGO during the preoperative outpatient follow-up. ⑤ tumor located in the outer 1/3 of the lung field. ⑥ multiple nodules in this operation only dealt with the main tumor. ⑦ all patients underwent multiport thoracoscopic surgery. The exclusion criteria included: ① benign lesions on pathology. ② multiple tumors requiring multiloculated resection. ③ enlarged lymph nodes detected on computed tomography (CT) evaluated preoperatively by positron emission tomography-computed tomography (with optional endobronchial ultrasound-guided transbronchial needle aspiration). Patients with confirmed metastasis of lymph nodes underwent lobectomy with systemic lymph node dissection. ④ previous surgery on the other

lung. ⑤ patients who could not tolerate surgery or general anesthesia. ⑥ patients requiring enlargement of the surgical area based on frozen section or intraoperative exploration (e.g., operative blood loss, insufficient or positive margins, calcification of lymph nodes) or who needed to open the chest immediately (e.g., major blood loss, severe pleural adhesion). ⑦ patients with severe combined basic diseases that may affect the test results.

Based on whether the target segment bronchus and remaining vessels were separated and dissected, the patients were divided into two groups: the watershed segmentectomy group and the anatomic segmentectomy group.

Structures divided in the two surgical approaches

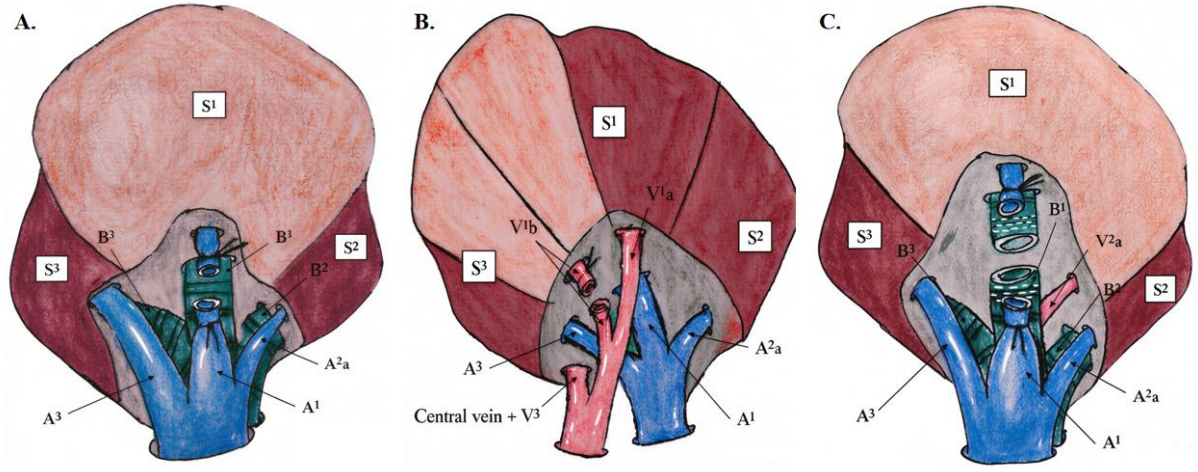


Fig. 1 Illustration of different transected structures in watershed segmentectomy and anatomical segmentectomy. (A) Watershed segmentectomy with division of A1; (B) Watershed segmentectomy with division of V1b; (C) Anatomical segmentectomy with division of A1 and B1.

Data collection

General patient information included: name, sex, age, comorbidities, smoking and drinking status, body mass index (BMI), maximum tumor diameter, and tumor location in the lobe.

Surgery-related information included: range of surgical resection, surgical duration, blood loss during the procedures, intraoperative consumables used (measured by the number of staples), whether the tumor was entirely resected during surgery, number of lymph nodes, frozen section results, and postoperative pathology results.

Postoperative situation and complications included: total postoperative hospital stay, postoperative tube duration, drainage during the first three days after surgery, and total drainage volume. In-hospital complications included pulmonary atelectasis, chylothorax, persistent air leak (duration of air leak > 5 days), secondary postoperative pneumothorax, and pulmonary infection. Patients with adenocarcinoma in situ (AIS) or minimally invasive adenocarcinoma (MIA) underwent chest CT scans, while those with invasive adenocarcinoma underwent head, chest, and abdominal CT scans every three months during the first two years and every six months for the following 3-5 years. The number of patients with a pulmonary infarction ≥ 1 cm on CT was counted during follow-up.

Data analysis

Quantitative data were summarized using the number of cases, mean, and standard deviation, while qualitative data were summarized using numbers and percentages. The data were compared using SPSS 25.0. The MEAN ± SD was used for measurements that conformed to a normal distribution, the median [interquartile range, IQR] was used for data with a non-normal distribution, and qualitative data were expressed as a ratio (%). The Shapiro-Wilk test was conducted on each dataset, and when a non-normal distribution was observed, clinical experience was used to determine the normality of the clinical parameters. T-tests were used for normally distributed data, and the Mann-Whitney U test was used for non-normally distributed data. Qualitative data were analyzed using the chi-squared test or Fisher's exact test. P-values of 0.05 or lower were considered statistically significant.

Results

This study included 327 patients who underwent sublobectomy based on the inclusion and exclusion criteria. Among them, 181 and 146 patients underwent watershed segmentectomy and anatomic segmentectomy, respectively (Fig. 2). The general patient information is presented in Table 1. Table 2 presents the distribution of targeted segments in the two groups.

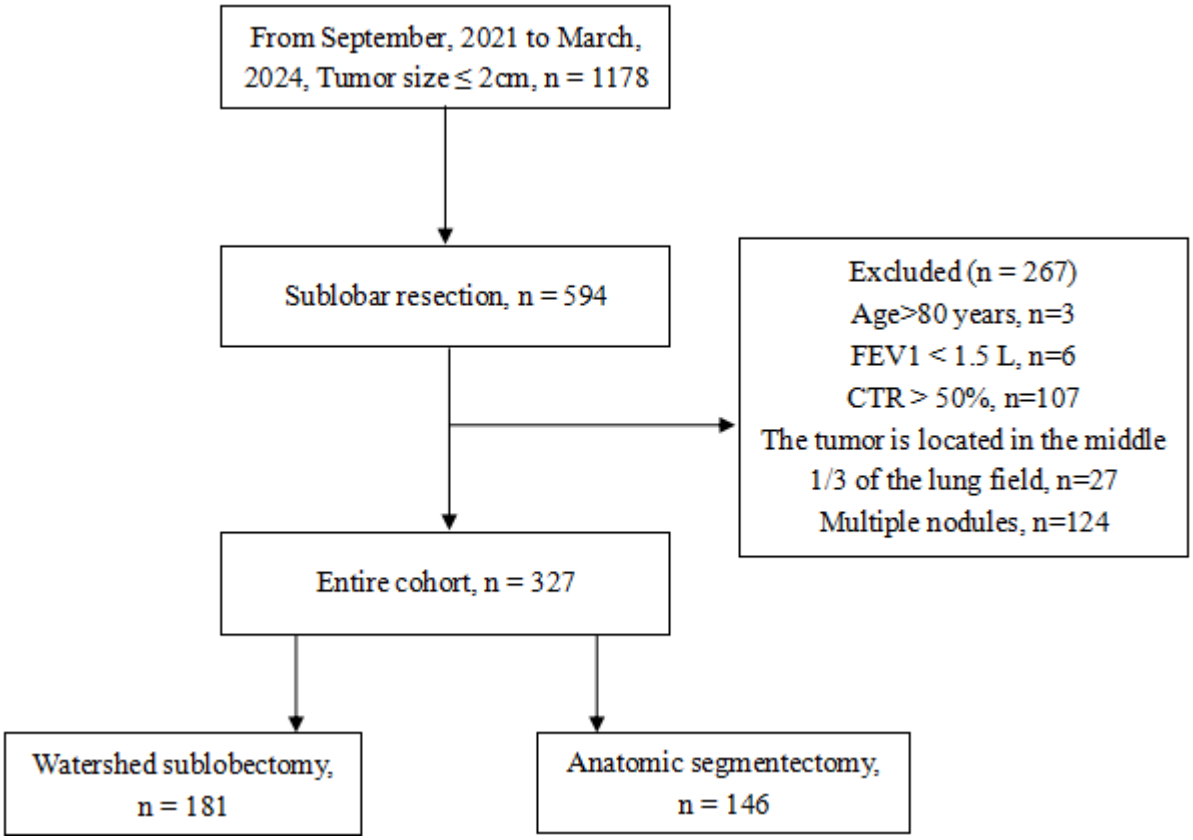


Fig. 2 Patient flow diagram

Table 1. Comparison of clinical characteristics information between the two groups

Variables	watershed segmentectomy group (n=181)	anatomic segmentectomy group (n=146)	Tests statistic	*P* Value
Age(y)	53.23±12.02	54.69±10.88	t=2.671	0.256

Gender = Female (%)	131 (72.4)	94 (64.4)	χ^2=0.679	0.149
Height (cm)	160.61±7.54	161.43±6.99	t=1.014	0.311
Body weight (kg)	59.54±9.04	61.37±10.53	t=1.694	0.091
BMI (kg/m)$^{2)}$	23.01±2.54	23.48±3.32	t=1.419	0.157
Smoking History = Yes (%)	23.01 (2.54)	30 (20.5)	χ^2=2.621	0.105
Maximum tumor diameter (mm)[IQR]	9 [7, 12]	10 [8, 15]	Z=2.864	0.003
Lung lobe where tumor is located (%)			χ^2=2.506	0.644
Right upper lung	62 (34.3)	46 (31.5)		
Right middle lung	14 (7.7)	10 (6.8)		
Right lower lung	17 (9.4)	19 (13.0)		
Left upper lung	62 (34.3)	44 (30.1)		
Left lower lung	26 (14.4)	27 (18.5)		
EF	65.96±4.21	65.73±4.27	t=0.484	0.629
LVEDD	45.39±3.38	45.55±4.65	t=0.359	0.720
LVESD	29.02±2.49	29.41±4.33	t=0.940	0.348
FVC actual value (L)	3.33±0.73	3.37±0.64	t=0.504	0.615
FVC expected value (L)	2.97±0.71	3.04±0.60	t=0.949	0.343
MVV actual value (L)	96.80±22.77	101.76±28.36	t=1.662	0.098
MVV expected value (L)	96.46±17.86	98.17±15.35	t=0.867	0.387
FRC actual value (L)	2.91±0.75)	3.16±0.93	t=2.548	0.011
FRC expected value (L)	2.78±0.57	2.82±0.38	t=0.606	0.545
FEV1 actual value (L)	2.61±0.61	2.63±0.49	t=0.255	0.799
FEV1 expected value (L)	2.47±0.58	2.53±0.46	t=0.926	0.355
DLCO actual value (ml-kPa-1/s)	6.89±1.60	6.94±1.55	t=0.295	0.768
DLCO expected value (ml-kPa-1/s)	7.81±1.17	7.82±0.99	t=0.055	0.956

Abbreviation：*BMI,* Body mass index; *EF,* ejection fraction; *LVEDD,* left ventricular end diastolic diameter; *LVESD,* left ventricular end systolic diameter; *FVC,* forced vital capacity; *MVV,* maximum ventilation volume; *FRC,* functional residual capacity; *FEV1,* forced expiratory volume in one second; *DLCOSB,* diffusing capacity of the lungs for carbon monoxide.

Table 2 Contribution of targeted segments in two group

Lobe	Segment	watershed segmentectomy group (n=181)	anatomic segmentectomy group (n=146)
Right			
Right upper lung	S1	28	19
	S2	17	17
	S3	17	10
Right middle lung	S4	12	9
	S5	2	1
	S6	8	5
Right lower lung	S7	0	1
	S8	6	4
	S9	1	4
	S10	2	5
Left			
Left upper lung	S1+2	38	22
	S3	18	16
	S4	6	4
Left lower lung	S5	0	2
	S6	10	13

S7+8	3	2
S9	5	3
S10	8	9

We analyzed and compared the perioperative parameters in both groups. The watershed segmentectomy group had a significantly shorter surgical duration, less blood loss, fewer staples, and fewer lymph nodes dissected than the anatomic segmentectomy group (P<0.001). There were no significant differences between the two groups in terms of frozen margins and tumor stage distribution (Table 3).

Table 3. Comparison of perioperative data between the two groups

Variables	**watershed segmentectomy group (n=181)**	**anatomic segmentectomy group (n=146)**	**Tests statistic**	***P* Value**
Surgical duration (min)	80 [60, 95]	90 [80, 105]	Z=6.015	<0.001
Blood loss (ml)	50 [50, 50]	100 [50, 100]	Z=4.161	<0.001
Number of staples [IQR]	4 [4, 5]	6 [5, 7]	Z=9.346	<0.001
Lymph node dissection				
N1 sampling (%)	159 (87.8)	139 (95.2)	χ^2=5.417	0.020
N2 sampling (%)	57 (31.5)	64 (43.8)	χ^2=5.282	0.022
The number of lymph nodes dissected [IQR]	2 [1, 4]	4 [2, 6]	Z=5.033	<0.001
Frozen section of lung margins = Negative (%)	181(100)	146(100)		
Pathological stage (%)			χ^2=4.517	0.104
0 stage	81 (44.8)	53 (36.3)		
IA1 stage	79 (43.6)	65 (44.5)		

IA2 stage	21 (11.6)	28 (19.2)

The watershed segmentectomy group had significantly less drainage volume in the first three postoperative days and in total compared to the anatomic segmentectomy group (P<0.05). No significant differences were observed between the groups in terms of unplaced tubes, air leakage, postoperative recurrent pneumothorax, postoperative bleeding, and other postoperative parameters. The watershed segmentectomy group also had a significantly shorter total hospital stay and fewer postoperative in-hospital complications (P<0.05). Furthermore, there was no significant difference between the two groups in the presence of pulmonary infarction >1 cm on the follow-up CT (Table 4).

Table 4. Comparison of postoperative data between the two groups

Variables	**watershed segmentectomy group (n=181)**	**anatomic segmentectomy group (n=146)**	**Tests statistic**	***P* Value**
Day 1 drainage volume (ml)	140 [100, 210]	180 [111.25, 250]	Z=2.754	0.006
Day 2 drainage volume (ml)	137.5 [100, 182.5]	160 [100, 217.5]	Z=2.721	0.007
Day 3 drainage volume (ml)	100 [80, 120]	100 [100, 120]	Z=2.314	0.021
Total drainage volume (ml)	330 [211, 477.5]	445 [317.5, 592.5]	Z=4.123	<0.001
Postoperative days with tubes (d)	3.00 [2.00, 3.00]	3 [2.75, 3]	Z=2.906	0.004
Total hospitalization cost (¥)	49936.40±6059.37	53585.06±7731.54	t=4.784	<0.001
No tube placed (%)	27 (14.9)	16 (11.0)	χ^2=1.109	0.292
Air leakage (%)	1 (0.6)	5 (3.4)		0.093
Postoperative recurrent pneumothorax (%)	0(0.0)	1 (0.7)		0.446
Post-operative bleeding	0 (0.0)	1 (0.7)		0.446
In-hospital postoperative complications (%)	1 (0.6)	7 (4.8)		0.024

Patient number of follow-up CT	85	102		
pulmonary infarction (%)	19 (22.4)	21 (20.6)	χ^2=0.086	0.769

DISCUSSION

In this study, watershed segmentectomy simplified the surgical procedure, shortened operative time, and reduced blood loss compared with anatomic segmentectomy, while maintaining a safe surgical margin. And there was no significant between-group difference in the intrapulmonary tumor distribution within the lobe, and watershed segmentectomy was feasible for all segmentectomies (e.g., S9, S10). This procedure is a balanced strategy between anatomic segmentectomy and wedge resection, combining the simplicity and speed of wedge resection with anatomic segmentectomy accuracy.

Watershed segmentectomy resulted in lower lymph node clearance than anatomic segmentectomy, with 29 patients not undergoing N1 lymph node sampling. We reviewed frozen sections and pathological results of patients with AIS or MIA. Previous studies have demonstrated that the 5-year recurrence-free survival rate for AIS or MIA is nearly 100%, with no regional lymph node metastasis (12). Additionally, a study suggested that mediastinal lymph node dissection is unnecessary in lung cancer patients with GGO nodules and a CTR $\leq$ 0.5 (13). Therefore, the absence of N1 group lymph node sampling did not affect postoperative survival. If tumors are solid, standard anatomic segmentectomy may be considered to accurately assess the regional lymph nodes.

In our study, the in-hospital complication rate in the anatomic segmentectomy group was 4.8%, which was lower than that in Kazuki's (8%) and Shen's (9.7%) (14, 15). This may be because of the exclusion of complex segmental resections. Moreover, it has been suggested that pulmonary atelectasis or recurrent pneumothorax may be caused by different surgical approaches (wedge resection,

segmentectomy, lobectomy) (16, 17). Our study supports this finding. The chest tube is a significant cause of postoperative pain and may prolong hospital stay without reducing the possibility of recurrent pneumothorax (16, 18). Watershed segmentectomy was superior to anatomic segmentectomy in terms of drainage volume and in-hospital complications, providing favorable conditions for not placing a chest tube.

In segmentectomy, there is often too much non-functional lung tissue remaining or too much normal lung tissue dissected (19). Some studies placed staples approximately 1 cm outside the intersegmental plane to ensure a safe margin (20). This was also performed in this study. However, more residual lung tissue may remain after watershed segmentectomy than after anatomic segmentectomy because of the lack of bronchial dissection. Based on intraoperative blockage of the pulmonary artery or vein, pathological changes in the residual lung tissue may resemble pulmonary embolism to pulmonary infarction. Moreover, existing connections between bronchial and pulmonary arteries in secondary lobules may replenish the blood supply to the lung and establish new circulation in an emergency, such as pulmonary embolism (21). On the other hand, if there is no bronchial artery to replenish blood for pulmonary embolism, the surrounding lung begins to necrotize, and infarction occurs. A fibrotic scar on CT eventually replaces the infarcted area after several months (22, 23). In our study, there were no statistically significant differences in the incidence of pulmonary infarction between the two groups.

Our study has several limitations. First, because this was a single-center retrospective study, it had an inherent retrospective nature and patient selection bias. Second, as a newly proposed surgical method, we lack long-term data on watershed segmentectomy and focus on follow-up of long-term outcomes. The risk of recurrence is attributed to inadequate surgical margin distance and insufficient lymph node evaluation (24, 25). The watershed segmentectomy had adequate surgical margins and underwent lymph

node evaluation. Moreover, all patients had negative intraoperative frozen sections of margins. Therefore, regarding clinical endpoints, the long-term prognosis of watershed segmentectomy may be better than that of wedge resection with subjective margins and without lymph node evaluation and may be comparable to anatomic segmentectomy. Finally, we did not collect postoperative pulmonary function data from the patients. According to the JCOG0802 trial, the difference in postoperative pulmonary function between lobectomy and segmentectomy is approximately 3% (2). Since both watershed segmentectomy and anatomic segmentectomy are sublobar resections, the difference in postoperative pulmonary function between the two might be even smaller.

CONCLUSION

This study suggests that watershed segmentectomy effectively reduces the surgical duration, blood loss, drainage volume, and complications. A preoperative three-dimensional margin evaluation is crucial. watershed segmentectomy could be a viable sublobectomy for selected patients, potentially supporting day surgery; however, multicenter studies are needed.

List of abbreviations

GGO, ground glass opacity

CTR, consolidation-to-tumor ratio

CT, computed tomography

BMI, body mass index

IQR, interquartile range

Declarations

Ethics approval and consent to participate

This retrospective study was approved by the Ethics Committee of The First Affiliated Hospital of Chongqing Medical University (2022-K101). All included patients provided written informed consent before surgery.

Consent for publication

Written informed consent for data use and publication was obtained from all patients. All data were anonymized prior to analysis; therefore, no identifiable personal data or images are included in this manuscript.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to patient privacy and institutional regulations but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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No funding was received for this study.

Authors' contributions

D.Y.L. conceived and designed the study, established and refined the methodology, collected and curated the data, performed all statistical analyses, interpreted the findings, generated all figures and tables, coordinated the research team, and wrote the original manuscript.

S.W.J. contributed substantially to study design, methodology, data acquisition, supported data analysis, and interpretation of results, and critically revised the manuscript.

Z,M, G.M.J. contributed to methodology, supported data analysis, participated in interpretation of results, and provided critical revisions of the manuscript.

All authors read and approved the final manuscript.

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