

# Pain Catastrophizing After Early-Stage Lung Cancer Surgery: The Mediating Effects of Interoceptive Awareness, Negative Attentional Bias, and Social Support

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**Background:** Pain Catastrophizing (PC) is a prevalent maladaptive cognitive - affective response after lung cancer surgery, linked to poor outcomes. The mechanisms between sub - acute pain and PC development within 3 months are unclear. Conventional pain management often neglects psychological and social factors related to PC and recovery. According to the biopsychosocial model, multiple factors are associated with PC, but their mediating pathways are not fully understood. Therefore, grounded in the stress and coping theory and the pain threat appraisal theory, first examines the multiple-parallel mediating roles of introspection, negative attentional bias, and social support between pain intensity and PC in early-stage lung cancer patients post - surgery.

**Methods:** A cross-sectional study recruited 414 early-stage lung cancer patients within 3 months post-surgery from ambulatory care follow-up and day ward treatment at a tertiary hospital from May to August 2025. Questionnaires were used for investigation, and parallel mediation was tested by structural equation modeling.

**Results:** The average PCS score was  $30.49 \pm 6.27$ . PC was positively correlated with pain intensity, interoceptive awareness, and negative attentional bias, and negatively correlated with social support. Interoceptive awareness, negative attentional bias, and social support together accounted for 59.81% of the total effect, with social support having the most prominent effect (31.05%)—substantially larger than interoceptive awareness (5.51%) and negative attentional bias (5.91%).

**Conclusion:** Post-operative PC levels in early-stage lung cancer patients are moderate to high. Pain intensity is directly and indirectly related to PC. Healthcare professionals are advised to develop a multidimensional, phased, and integrated intervention framework including pain management, cognitive behavioral therapy, and mindfulness training. This approach can effectively reduce PC and support precise prevention and intervention.

**Keywords:** lung cancer, postoperative pain, pain catastrophizing, interoceptive awareness, negative attention bias, social support, mediating effects

## Introduction

Lung cancer is the most prevalent and lethal malignant tumor globally, presenting a significant public-health challenge.<sup>1</sup> With growing public-health awareness and advancements in early cancer screening, its incidence has been rising steadily. However, effective management of postoperative pain remains a major clinical obstacle. Although thoracoscopic surgery reduces surgical trauma, about 80% of patients still suffer from varying degrees of postoperative pain. This not only hinders recovery but may also increase the risk of disease recurrence.<sup>2</sup> Studies<sup>3-5</sup> show that the incidence of post-operative pain among lung cancer patients within three months after surgery is 56–69%, and 15–60% of them may develop chronic pain.

Currently, traditional pain-management strategies primarily focus on pharmacological interventions and pain assessment, neglecting psychological and social factors. This may lead to pain catastrophizing in patients, negatively affecting postoperative recovery.<sup>6</sup> Thus, assessing pain catastrophizing levels is of great clinical significance. Pain catastrophizing is a maladaptive cognitive-emotional response, where individuals overstate pain threats, experience more distress, and feel a lack of control.<sup>7</sup> Research indicates that 20–35.3% of postoperative lung cancer patients have PCS scores  $\geq 38$ ,<sup>8–10</sup> highlighting the clinical significance of assessment.

According to the biopsychosocial model, pain catastrophizing is influenced by multiple interrelated factors including biological mechanisms, psychological states, and social support. Existing evidence suggests that pain intensity,<sup>7</sup> interoceptive awareness,<sup>11,12</sup> negative attentional bias,<sup>13</sup> and perceived social support<sup>14</sup> are key factors. Interoceptive awareness is an individual's ability to detect and regulate internal physiological signals, related to cognitive and behavioral regulation.<sup>15</sup> Negative attentional bias is a cognitive tendency to focus on negative stimuli while ignoring neutral or positive information.<sup>16</sup>

Despite these known factors, the specific mediating pathways among pain intensity, interoceptive awareness, negative attentional bias, and social support in the development of pain catastrophizing remain unexamined in early-stage lung cancer patients. Grounded in Stress and Coping Theory and Pain Threat Interpretation Theory,<sup>17,18</sup> this study is among the first to test the multiple parallel mediating roles of these three variables in the pain-catastrophizing relationship. This work addresses a critical gap by simultaneously examining these mechanisms within a single integrated biopsychosocial model.

Therefore, this study puts forward the following two central research questions: (1) Mediation mechanism: Do interoceptive awareness, negative attentional bias, and social support significantly mediate the relationship between pain intensity and pain catastrophizing among patients following early-stage lung cancer surgery? (2) Multiple mediation pathways: Are there multiple parallel mediation pathways through which interoceptive awareness, negative attentional bias, and social support influence the relationship between pain intensity and pain catastrophizing? If so, what is the relative importance of each pathway? Answering these questions will lay a solid theoretical foundation for the prevention of pain catastrophizing and the development of targeted rehabilitation.

## Materials and Methods

### Study Design

A cross-sectional study design was employed to investigate patients who had undergone early-stage lung cancer surgery and were attending follow-up visits at ambulatory care and day ward treatment of a tertiary grade A specialized hospital in Tianjin from May to August 2025. These individuals were selected as research participants through convenience sampling, and relevant data were collected via face-to-face interviews.

### Participants

Eligibility criteria for patients: (1) Diagnosis of lung cancer confirmed by imaging and pathological examinations, and meeting the staging criteria for early-stage lung cancer as defined in the Chinese Medical Association guideline for clinical diagnosis and treatment of lung cancer (2024 Edition);<sup>19</sup> (2) Completion of curative lung resection surgery with discharge within 3 months postoperatively; (3) Age  $\geq 18$  years; (4) Sufficient cognitive and language abilities to understand and complete the questionnaire independently or with minimal assistance; (5) Provision of written informed consent prior to participation. Exclusion criteria: (1) Presence of diagnosed psychiatric disorders or a history of receiving formal psychological or psychiatric treatment; (2) Significant comorbidities involving major organ systems, including severe cardiac, pulmonary, hepatic, or renal dysfunction. Dropout criteria: (1) Missing data exceeding 5% in key scale items or essential clinical records; (2) Evidence of systematic or patterned responding on questionnaires, indicating non-compliance or invalid responses. Based on the sample size estimation method proposed by Kendall,<sup>20</sup> which recommends that the sample size should be 10 to 20 times the number of independent variables, this study included 33 independent variables and used a multiplier of 11, resulting in a minimum required sample size of 363. Accounting for a 10% questionnaire invalidity rate and considering clinical feasibility, the final target sample size was set at 414 participants.

## Procedure

Four nurses who had received standardized training and possessed clinical experience were selected as study investigators. Two nurses were assigned to the outpatient department and two to the day ward to conduct the questionnaire administration. After obtaining informed consent, patients in the day ward completed the questionnaires at their bedside, while those in the outpatient setting completed them in a quiet waiting area. Investigators delivered standardized verbal instructions to explain the study purpose and questionnaire completion procedures, ensuring that participants completed the questionnaires independently and truthfully. Upon completion, each questionnaire was immediately reviewed on site by the investigator; any missing or incomplete items were identified and addressed with the participant before final submission. Once completeness was confirmed, the questionnaires were collected on the spot. A total of 425 questionnaires were distributed, and 414 valid responses were obtained, yielding an effective response rate of 97.4%. Ethical approval for the study was obtained from Tianjin Medical University Cancer Institute & Hospital (bc20252060), with conduct in strict adherence to Helsinki Declaration guidelines.

## Measures

### General Information on the Questionnaire

The questionnaire was developed by the research team based on a comprehensive review of relevant literature and expert group discussions. It comprises two sections: general demographic information and disease-related characteristics. Demographic variables include gender, age, marital status, educational attainment, occupation, place of residence, living arrangement, household income, medical payment method, and personality traits. Disease-related variables encompass time since surgery, prior medical history, body mass index (BMI), preoperative pain experience, long-term use of analgesic medications, sleep quality, postoperative treatment regimen, and pathological stage.

### Pain Catastrophizing Scale (PCS)

The Pain Catastrophizing Scale (PCS) was developed by Sullivan et al<sup>21</sup> in 1995 to assess the tendency of individuals to engage in catastrophic thinking in response to pain. It is currently the most widely used instrument for evaluating pain-related catastrophizing in clinical settings. The scale was specifically designed to measure the severity of pain catastrophizing and comprises 13 items distributed across three subscales: helplessness, magnification, and rumination. Each item is rated on a 5-point Likert scale ranging from 0 (“never”) to 4 (“always”), yielding a total score between 0 and 52. A cutoff score of  $\geq 30$  has been established as clinically significant,<sup>16</sup> indicating the presence of notable pain catastrophizing, with higher scores reflecting greater severity. The Chinese version of the scale was translated and culturally adapted by Yap et al<sup>22</sup> in 2008. In this study, the scale demonstrated strong internal consistency, with an overall Cronbach’s  $\alpha$  coefficient of 0.864, confirming its reliability and validity.

### Pain Assessment Ruler

The Pain Assessment Ruler<sup>23,24</sup> integrates three single-dimensional pain scales—the Numerical Rating Scale (NRS), Verbal Descriptor Scale (VDS), and Revised Faces Pain Scale (FPS-R)—as coordinated response options where the NRS serves as the primary quantitative outcome measure for statistical analyses. The VDS and FPS-R function as supplementary visual and verbal anchors to assist patients, particularly older adults, in accurately selecting their NRS score. The NRS employs an 11-point numeric scale ranging from 0 (“no pain”) to 10 (“worst possible pain”), with scores of 0–3 indicating mild pain, 4–6 moderate pain, and 7–10 severe pain. The VDS provides descriptive verbal anchors from “no pain” to “severe pain,” while the FPS-R depicts six facial expressions representing increasing pain levels from “no pain” to “very much pain.” This integrated design ensures simplicity, efficiency, and enhanced accuracy for pain assessment in older adults by facilitating reliable NRS scoring.

### The Multidimensional Assessment of Interoceptive Awareness, Version2 (MAIA-2)

In 2018, Mehling et al revised the Multidimensional Assessment of Interoceptive Awareness (MAIA) to develop the second edition (MAIA-2).<sup>25</sup> Relative to the original version, MAIA-2 retains eight dimensions and comprises 37 items. It employs a 6-point Likert scale ranging from 0 (“never”) to 5 (“always”), with higher scores indicating greater interoceptive awareness. To improve content coverage and measurement precision, three items were added to the “Not

Distracted” dimension and two items to the “Not Worrying” dimension. The Chinese version of the MAIA-2 (MAIA-2C) was translated and culturally adapted in 2022,<sup>26</sup> and its psychometric properties were validated in a mainland Chinese population. In this study, the scale demonstrated excellent internal consistency, with an overall Cronbach’s  $\alpha$  coefficient of 0.920, confirming its reliability and validity.

### The Chinese Attention to Negative Inventory (ANI)

The Attention to Positive and Negative Information Inventory (APNI), developed by Dai Qin et al<sup>27</sup>, has undergone translation and cultural adaptation to produce a Chinese version. It comprises two subscales: the Positive Information Attention Scale and the Negative Information Attention Scale. The Chinese version of the Negative Information Attention Scale consists of 10 items organized across two dimensions: self and others. It utilizes a 5-point Likert scoring system (ranging from 1 to 5), with total scores varying between 10 and 50; higher scores reflect a stronger negative attentional bias. The subscale demonstrates a Cronbach’s  $\alpha$  coefficient of 0.82 and a test-retest reliability coefficient of 0.62. For the Positive Information Attention Scale, the Cronbach’s  $\alpha$  coefficient is 0.86, with a test-retest reliability of 0.79. Research indicates that the correlation between the two subscales is low, suggesting good discriminant validity and supporting their independent use in clinical or research settings to assess attentional biases toward positive and negative information. In this study, the Chinese version of the Negative Information Attention Scale was employed for assessment purposes. It exhibited strong internal consistency in the current sample, with an overall Cronbach’s  $\alpha$  coefficient of 0.887, confirming its reliability and validity as a measurement tool.

### Social Support Rating Scale (SSRS)

The Social Support Rating Scale (SSRS),<sup>28</sup> developed by Shuiyuan Xiao at Hunan Medical University in China in 1986, is a widely used instrument designed to assess individuals’ perceived levels of social support. The scale comprises 10 items distributed across three dimensions: objective support (items 2, 6, and 7), subjective support (items 1, 3, 4, and 5), and utilization of support (items 8, 9, and 10). The maximum total score is 66. Scoring is conducted as follows: items 1–4 and 8–10 are rated on a 4-point scale, with responses 1 to 4 assigned scores of 1 to 4, respectively. Item 5 consists of five sub-items (A, B, C, D, and E), each scored from 1 to 4 according to the level of support—from “none” to “full support”—and the sum of these sub-item scores constitutes the total for item 5. For items 6 and 7, a response of “no source” is scored as 0, while endorsement of “the following sources” yields one point per identified source. Higher total scores indicate greater levels of perceived social support. Based on established normative criteria, scores  $\leq 22$  reflect low social support, scores ranging from 23 to 44 reflect moderate social support, and scores  $\geq 45$  indicate high social support. In this study, the SSRS demonstrated strong internal consistency, with an overall Cronbach’s  $\alpha$  coefficient of 0.836, confirming its reliability and validity as a psychometric tool.

## Data Analysis

Data were entered using Microsoft Excel and independently double-entered by two researchers to ensure accuracy. Data analysis was performed with SPSS 26.0 including descriptive statistics of pain catastrophizing (such as mean, standard deviation, etc.) and Pearson correlation analysis to examine the relationships among pain intensity, interoceptive awareness, negative attentional bias, social support, and pain catastrophizing.

A structural equation model (SEM) was subsequently constructed using AMOS 24.0 to test the mediating effects of interoceptive awareness, negative attentional bias, and social support in the relationship between pain intensity and pain catastrophizing. Notably, variables associated with pain catastrophizing (PCS) identified in univariate analysis (eg, marital status, analgesic use, pathological stage) were excluded from the SEM model. This exclusion was because this decision was grounded in the study’s theoretical focus on testing the mediating mechanisms of interoceptive awareness, negative attentional bias, and social support within a biopsychosocial framework. As these three variables constitute the core cognitive-affective processes directly underlying PCS, their inclusion, as primary mediators, enhanced the model’s internal validity and explanatory power. While the omitted demographic and clinical variables may indirectly influence PCS by affecting these core mediators, they were excluded to maintain model parsimony and concentrate analytical power on the hypothesized mediating pathways, which represented the central focus of this research. The significance of

indirect effects was evaluated using the Bootstrap method with 5000 resamples at a 95% confidence interval. The statistical significance level was set at  $\alpha = 0.05$ .

## Results

### Result of the Common Method Bias Test

The Harman single-factor test was employed to assess common method bias. All items from the Chinese version of the PCS, the Pain Assessment Scale, MAIA-2, the Chinese version of the ANI, and the SSRS were included in an unrotated exploratory factor analysis for patients who underwent surgery for early-stage lung cancer. The analysis yielded 15 factors with eigenvalues exceeding 1. The first factor accounted for 21.75% of the total variance, which is below the 40% threshold, indicating no significant common method bias in the study.

### Descriptives

In the univariate analysis of factors influencing pain catastrophizing in patients after early-stage lung cancer surgery, statistically significant factors included marital status, personality traits, operation time, duration of pain, long-term use of analgesics, sleep quality, the number of days pain restricted daily life or work, treatment methods, and pathological stage ( $P < 0.05$ ). For details, please refer to [Table 1](#).

The mean pain severity score among patients who underwent surgery for early-stage lung cancer was  $3.22 \pm 1.13$ , interoceptive awareness was  $109.33 \pm 5.89$ , negative attentional bias toward information was  $29.24 \pm 6.72$ , and perceived social support was  $40.06 \pm 6.80$ . Further details are in [Table 2](#).

**Table 1** Univariate Analysis Of Demographic Data Of Patients with Early-Stage Lung Cancer After Surgery

Variables	Total Sample (N=414) N (%)	PCS, (Mean $\pm$ SD)	t/F	P
Marital status				
Unmarried	12(2.9)	35.50 $\pm$ 5.75	3.406**	0.018
Married	371(89.6)	30.29 $\pm$ 6.30		
Divorced	16(3.9)	32.44 $\pm$ 4.24		
Widowed	15(3.6)	29.40 $\pm$ 6.16		
Personality traits				
Extraversion	120(29.0)	29.43 $\pm$ 6.59	7.823**	<0.001
Agreeableness	104(25.1)	29.68 $\pm$ 6.73		
Rigorousness	109(26.3)	30.94 $\pm$ 5.76		
Openness	45(10.9)	31.00 $\pm$ 4.11		
Neuroticism	36(8.7)	35.47 $\pm$ 4.06		
Postoperative time				
One month	276(66.7)	29.96 $\pm$ 6.79	-2.465*	0.014
One to three months	138(33.3)	31.56 $\pm$ 4.93		
Duration of pain				
Short-term ( $\leq 14$ )	226(54.6)	28.92 $\pm$ 6.64	21.216**	<0.001
Medium term (15~30)	139(33.6)	32.17 $\pm$ 5.28		
Long-term ( $\geq 31$ )	49(11.8)	33.80 $\pm$ 3.59		
Long-term use of painkillers				
Yes	141(34.1)	33.13 $\pm$ 4.84	6.465*	<0.001
No	273(65.9)	29.12 $\pm$ 6.49		

(Continued)

**Table 1** (Continued).

Variables	Total Sample (N=414) N (%)	PCS, (Mean ± SD)	t/F	P
Sleep quality				
Very good	36(8.7)	28.44±7.95	9.052**	<0.001
Good	129(31.2)	29.10±5.69		
Average	212(51.2)	31.01±6.13		
Poor	37(8.9)	34.35±5.12		
Pain limits the number of days you can live or work.				
Never	47(11.4)	28.21±7.17	11.119**	<0.001
Some days	303(73.2)	30.12±6.09		
Most days	58(14.0)	33.38±4.67		
Every day	6(1.4)	39.17±6.43		
Treatment method				
Targeted therapy	180(43.5)	30.13±5.58	32.227**	<0.001
Immunotherapy	57(13.8)	33.09±5.48		
Immune therapy + Chemotherapy	57(13.8)	35.63±7.12		
No	120(29.0)	27.35±5.05		
Pathological stage				
I	325(78.5)	29.26±5.69	-9.150*	<0.001
II	89(21.5)	35.45±5.56		

**Notes:** \*Indicates the t-value, \*\*Indicates the F-value.

**Abbreviation:** SD, standard deviation.

**Table 2** Pain Severity, Interoceptive Awareness, Negative Attentional Bias, Social Support, and Pain Catastrophizing Scores Among Patients with Early-Stage Lung Cancer After Surgery (n = 414)

Variable	Number of Items	Score Range	Total Mean	Item Mean
Pain catastrophizing total score	13	0–52	30.49 ± 6.27	2.35 ± 0.48
Exaggeration	3	0–12	8.10 ± 2.07	2.70 ± 0.69
Rumination	5	0–20	12.65 ± 2.58	2.53 ± 0.52
Helplessness	5	0–20	9.74 ± 2.75	1.95 ± 0.55
Interoceptive Awareness Total Score	37	0–185	109.33 ± 15.89	2.95 ± 0.43
Awareness	4	0–20	12.55 ± 2.64	3.14 ± 0.66
Non-Distraction	6	0–30	20.04 ± 3.40	3.34 ± 0.57
Non-Worry	5	0–25	15.62 ± 2.96	3.12 ± 0.59
Attention Regulation	7	0–35	18.88 ± 3.83	2.70 ± 0.55
Emotional Awareness	5	0–25	15.07 ± 2.76	3.01 ± 0.55
Self-Regulation	4	0–20	11.55 ± 2.34	2.89 ± 0.58
Body Listening	3	0–15	7.88 ± 1.88	2.63 ± 0.63
Trust	3	0–15	7.74 ± 2.80	2.58 ± 0.93
Negative Attentional Bias Total Score	10	10–50	29.24±6.72	3.08±0.67
Self Dimension	5	5–25	14.70±3.68	2.94±0.73
Other Dimension	5	5–25	14.54±3.42	2.91±0.68
Social Support Total Score	10	12–62	40.06±6.80	4.01±0.68
Objective Support	3	1–18	9.26±2.03	3.09±0.68
Perceived Support Utilization	3	3–12	7.35±2.01	2.49±0.63
Subjective Support	4	8–32	23.46±4.2	1.84±0.52
Pain Intensity	1	0–10	3.22±1.13	3.22±1.13

## Correlations Analysis

Pain intensity was significantly positively correlated with the total scores of interoceptive awareness, negative attentional bias, and pain catastrophizing ( $P < 0.001$ ), and significantly negatively correlated with the total score of social support ( $P < 0.001$ ). The total score of interoceptive awareness was also significantly positively associated with the total scores of negative attentional bias and pain catastrophizing ( $P < 0.001$ ), and showed a significant negative correlation with the total score of social support ( $P < 0.001$ ). Furthermore, the total score of negative attentional bias was significantly positively correlated with the total score of pain catastrophizing ( $P < 0.001$ ), and significantly negatively correlated with the total score of social support ( $P < 0.001$ ). Lastly, a significant negative correlation was observed between the total score of social support and the total score of pain catastrophizing ( $P < 0.001$ ), as shown in Table 3.

## Structural Equation Model (SEM)

A structural equation model was constructed with pain catastrophizing as the dependent variable, pain intensity as the independent variable, and interoceptive awareness, negative attentional bias, and social support as mediating variables (Figure 1). Model fit indices ( $\chi^2/df = 2.663$ , GFI = 0.931, AGFI = 0.896, CFI = 0.945, NFI = 0.916, IFI = 0.946, TLI = 0.926, RMSEA = 0.063, SRMR = 0.056) all fall within acceptable thresholds, indicating good model fit and supporting the adequacy of the proposed model (Table 4). To examine the mediating effects of each pathway, 5,000 bootstrap samples were generated using the non-parametric percentile Bootstrap method, with a 95% confidence interval (Table 5).

## Discussion

### Prevalence and Clinical Profile of Postoperative Pain Catastrophizing

The mean PCS score of  $30.49 \pm 6.27$  slightly exceeds the clinical cutoff ( $\geq 30$ ), indicating moderately high pain catastrophizing in early-stage lung cancer patients within three months post-surgery.<sup>8–10</sup> The rumination subscale scored highest, reflecting persistent attentional focus on pain that exacerbates psychological distress.<sup>7,21</sup> Key risk factors include neurotic personality traits (8.7% of this sample),<sup>29</sup> long-term analgesic use (34.1%) indicating suboptimal pain control, and higher pathological stage (21.5% Stage II).<sup>6,30</sup> Notably, A PCS score 1–3 months post-surgery that is higher than 1 month post-surgery may be related to prolonged pain, which can trigger anxiety about recovery progress and disease recurrence, exacerbating catastrophic thinking. Given these findings, it is recommended that healthcare providers proactively identify high-risk patients—particularly those with neurotic traits, inadequate pain control, or prolonged pain—and integrate routine assessment of pain catastrophizing into standard clinical care. Moreover, cognitive-behavioral interventions should be implemented to assist patients in identifying and restructuring maladaptive pain-related cognitions, reducing rumination, and promoting active engagement in pain self-management strategies to enhance perceived control and ultimately reduce pain catastrophizing.

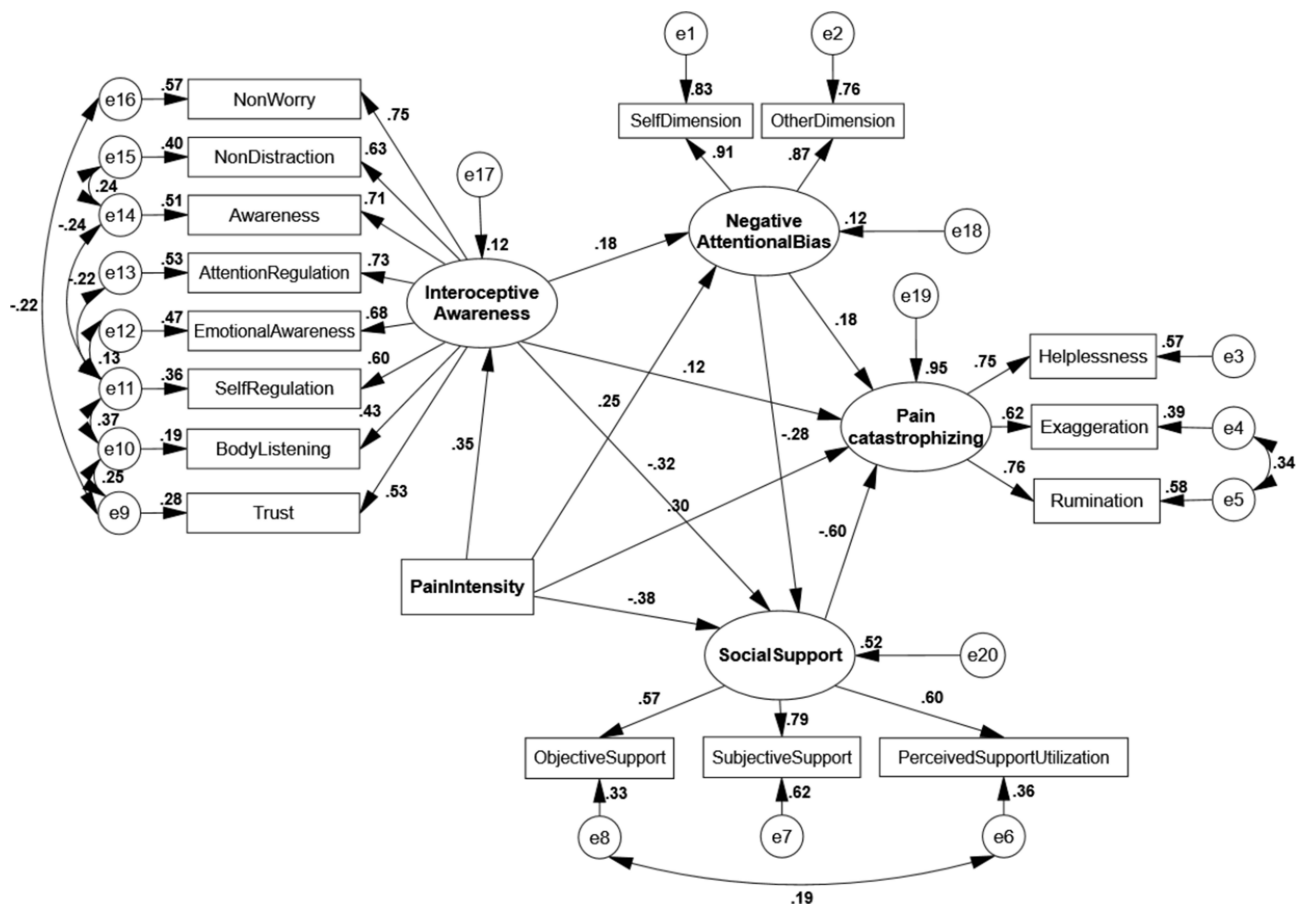
### Direct Effect of Pain Intensity

Correlation analysis revealed a significant positive association between pain intensity and catastrophizing ( $r = 0.636$ ,  $P < 0.001$ ), supporting pain threat interpretation theory<sup>18</sup> and consistent with prior research.<sup>6,10</sup> High-intensity pain acts as

**Table 3** Correlation Analysis of Pain Intensity, Interoceptive Awareness, Negative Attentional Bias, Social Support, and Pain Catastrophizing in Patients with Early-Stage Lung Cancer After Surgery (n = 414)

Variables	Pain Intensity	Interoceptive Awareness	Negative Attentional Bias	Social Support	Pain Catastrophizing
Pain Intensity	I				
Interoceptive awareness	0.322**	I			
Negative attentional bias	0.295**	0.233**	I		
Social Support	-0.493**	-0.670**	-0.390**	I	
Pain Catastrophizing	0.626**	0.458**	0.478**	-0.670**	I

**Notes:** \*\*Denotes a statistically significant correlation at the  $p < 0.001$  level (two-tailed).



**Figure 1** Mediating effect model of interoceptive awareness, negative attentional bias, and social support in the relationship between pain intensity and pain catastrophizing among patients with early-stage lung cancer after surgery.

a potent stressor that triggers fear and anxiety, leading patients to misinterpret pain as disease recurrence or deterioration. This creates a self-perpetuating cycle of pain vigilance and hypervigilance that reinforces maladaptive cognitive patterns.<sup>7,18</sup> SEM confirmed a significant direct effect ( $\beta = 0.299, P < 0.001$ ), with pain intensity accounting for 40.19% of the total effect on catastrophizing. Clinically, elevated pain scores should trigger psychological assessment and integrated non-pharmacological interventions (cognitive restructuring, attentional retraining, pain education) rather than sole reliance on analgesics.

**Table 4** Model Fit Indices

Model Fit Indices	The Fitting Standard or Critical Value	Fitting Results
Chi-Square to Degrees of Freedom Ratio ( $\chi^2/df$ )	1 - 3 (3-5 are acceptable)	2.663
Goodness-of-Fit Index (GFI)	> 0.9, 0.8-0.9 are acceptable	0.931
Adjusted Goodness-of-Fit Index (AGFI)	> 0.9, 0.8-0.9 are acceptable	0.896
Comparative Fit Index (CFI)	> 0.9, 0.8-0.9 are acceptable	0.945
Normed Fit Index (NFI)	> 0.9, 0.8-0.9 are acceptable	0.916
Incremental Fit Index (IFI)	> 0.9, 0.8-0.9 are acceptable	0.946
Tucker-Lewis Index (TLI)	> 0.9, 0.8-0.9 are acceptable	0.926
Root Mean Square Error of Approximation (RMSEA)	≤ 0.05 (high fitting degree), ≤ 0.08 (good fitting)	0.063
Standardized Root Mean Square Residual (SRMR)	≤ 0.05 (excellent), ≤ 0.08 (acceptable)	0.056

**Table 5** Standardized Mediating Effects Of Interoceptive Sensitivity, Negative Attentional Bias, and Social Support in The Relationship Between Pain Intensity and Pain Catastrophizing Among Patients with Early-Stage Lung Cancer After Surgery

Path	Effect Size	Proportion of the Mediated Effect	95% CI		P
			Lower Bound	Upper Bound	
Pain intensity → Interoceptive awareness → Pain catastrophizing	0.041	5.51%	0.010	0.082	0.018
Pain intensity → Negative attentional bias→ Pain catastrophizing	0.044	5.91%	0.014	0.083	0.006
Pain intensity → Social support → Pain catastrophizing	0.231	31.05%	0.147	0.361	<0.001
Pain intensity → Interoceptive awareness → Negative attentional bias→ Pain catastrophizing	0.011	1.48%	0.002	0.027	0.006
Pain intensity → Interoceptive awareness → Social support → Pain catastrophizing	0.067	9.01%	0.038	0.113	<0.001
Pain intensity → Negative attentional bias→ Social support → Pain catastrophizing	0.041	5.51%	0.017	0.086	<0.001
Pain intensity → Interoceptive awareness → Negative attentional bias→ Social support → Pain catastrophizing	0.010	1.34%	0.004	0.025	0.002
Total Indirect Effect	0.445	59.81%	0.348	0.578	<0.001
Direct Effect	0.299	40.19%	0.191	0.421	<0.001
Total Effect	0.744	100%	0.412	0.743	<0.001

## Multiple Mediating Pathways

The analysis revealed significant parallel and sequential mediating pathways. Interoceptive awareness, negative attentional bias, and social support collectively mediated 59.81% of the pain - catastrophizing relationship, highlighting the substantial role of psychosocial processes. Social support was the most prominent mediator (31.05% of the total effect). Higher pain intensity was linked to lower perceived social support, which in turn strongly predicted greater PC. Adequate support provides emotional reassurance and practical resources, enhancing pain coping self - efficacy, whereas its absence can exacerbate feelings of isolation and helplessness.<sup>14,31</sup> Interoceptive awareness reflects heightened bodily vigilance that amplifies routine sensations into threats,<sup>11,15,32</sup> and it accounted for 5.51% of the total effect. Negative attentional bias represents selective attention to pain - related negative stimuli that consolidates maladaptive cognitive patterns,<sup>13,16</sup> and it accounted for 5.91% of the total effect. These factors operate in sequence. Firstly, higher pain intensity leads to increased interoceptive awareness. Secondly, increased interoceptive awareness gives rise to negative attentional bias. Thirdly, negative attentional bias further results in diminished support utilization. Finally, diminished support utilization leads to pain catastrophizing, representing a cascading vulnerability sequence. A sequential pathway (pain intensity→interoceptive awareness/negative attentional bias→reduced social support→catastrophizing) underscores the interplay of biological, psychological, and social factors. This supports a multidimensional clinical framework: combine pain control, cognitive-behavioral therapy(CBT), mindfulness training, and social support enhancement to disrupt cascading maladaptive processes.

## Integrated Clinical Implications

These findings advocate for an integrated, multidimensional intervention framework grounded in the biopsychosocial model to address both the direct and mediated pathways to PC: (1) Effective Pain Management: As the foundational element to reduce the primary driver. (2) Social support is the most powerful psychosocial mediator of pain catastrophizing and should therefore be prioritized as highly as pharmacological pain control in clinical practice. Assessing and strengthening patients' social support networks must become an integral component of routine postoperative care. Social support optimization involves proactively engaging family caregivers, establishing peer support groups, and connecting patients with community resources. (3) Cognitive-behavioral strategies: Target attentional retraining and cognitive restructuring to disrupt rumination. (4) Mindfulness-based interventions: Teach non-judgmental interoceptive awareness

(eg, body scanning) to reduce catastrophic misinterpretation. (5) Risk stratification: Prioritize patients with neurotic traits, persistent analgesic requirements, and early postoperative status for intensive psychological support.

## Limitations and Future Directions

This study has several limitations. First, the single-center design may introduce selection bias via convenience sampling, thereby limiting generalizability to broader early-stage lung cancer surgery cohorts. Second, reliance on self-report measures risks response biases and subjective inconsistencies, including social desirability and variable interoceptive awareness ratings. Third, potential residual confounding from unmeasured variables—such as preoperative pain trajectories and psychological comorbidities—cannot be fully eliminated. Fourth, the cross-sectional design contributes to common method bias by collecting all data at a single time point, which may artificially inflate correlations and precludes establishing causal relationships or directional effects (eg, pain intensity versus catastrophizing). Finally, heterogeneity due to the 1–3 month postoperative window may obscure critical period-specific recovery patterns. Future research should employ multicenter, longitudinal, or interventional designs to confirm causal pathways and temporal dynamics. Integrating objective measures (eg, physiological indicators, attention bias tasks) with self-reports would enhance robustness.

## Conclusions

This study suggests that patients with early lung cancer exhibit moderate-high levels of pain catastrophizing within 3 months post-surgery, with pain intensity showing significant associations with catastrophizing through potential mediators of interoception, negative attentional bias, and social support. These findings generate hypotheses for intervention research, healthcare professionals should consider implementing a multidimensional intervention strategy: awareness-based interventions can regulate introspection, cognitive-behavioral therapy techniques can target negative attentional bias, and family education sessions or patient support groups can enhance social support. Such approaches may mitigate catastrophizing, though interventional studies are needed to test these hypotheses. However, the single-center, cross-sectional design limits generalizability and causal inference; future multi-center, longitudinal, or intervention studies are essential to validate these pathways, test causality, and evaluate intervention effectiveness.

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## Disclosure

The authors declare no conflicts of interest in this work.

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