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Development of a Pulmonary Rehabilitation Program for Patients with Pulmonary Hypertension in High-Altitude Areas of China: A Delphi study

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Abstract

Background

The incidence of pulmonary hypertension (PH) is significantly higher in high-altitude environments, where disease progression is also more rapid. Pulmonary rehabilitation (PR) is a core intervention for improving functional status in patients with chronic respiratory diseases. However, a systematic PR program specifically tailored for patients with PH in high-altitude areas is currently lacking.

Objective

To develop a PR program suitable for patients with PH in the Qinghai-Tibet Plateau region of China, thereby providing a scientific and feasible basis for clinical intervention.

Methods

A Delphi method was employed. An initial draft of the program was formulated through literature review and research team discussions. Seventeen experts were recruited to participate in two rounds of consultation. Experts rated the importance and feasibility of each item using a 5-point Likert scale and provided suggestions for modification. Consensus criteria were defined as mean score > 3.5, full-mark percentage > 20%, and coefficient of variation (CV) < 0.25.

Results

The effective response rates for the two rounds were 100% and 88.24%, respectively, and the expert authority coefficient was 0.835. After two rounds of consultation, the mean importance scores of items ranged from 4.13 to 5.00, the mean feasibility scores ranged from 3.87 to 4.67, and all CV were < 0.25. The Kendall's coefficients of concordance for all items increased from the first round to the second round, with values of 0.221 for importance and 0.197 for feasibility in the second round (both $P < 0.001$). The final program encompasses six domains, including multidisciplinary team, rehabilitation assessment, exercise prescription, health education, psychological support, and follow-up management, and comprises 6 first-level items, 27 second-level items, and 57 third-level items.

Conclusion

The PR program developed in this study for patients with PH in high-altitude areas demonstrates both environmental adaptability and clinical operability, providing a key reference framework for implementing PR in high-altitude areas.

1 Introduction

Pulmonary hypertension (PH) is a cardiopulmonary disease characterized by a progressive increase in pulmonary vascular resistance, which can ultimately lead to right heart failure and death [1]. Among its various classifications, Group 3 PH, caused by lung disease or chronic hypoxia, is a common clinical type. Its core mechanism involves chronic lung disease or prolonged hypoxic conditions leading to structural and functional abnormalities in the pulmonary vasculature, resulting in persistently elevated pulmonary vascular resistance and pulmonary arterial pressure, which can progress to right heart failure in severe cases [2, 3]. The Qinghai-Tibet Plateau in China, with an average elevation exceeding 4,000 meters and spanning approximately 2.5 million square kilometers [4, 5], is a typical high-altitude area. In such an environment, characterized by chronic hypoxia, low barometric pressure, cold temperatures, and intense ultraviolet radiation, the risk of developing PH is significantly increased, and disease progression is accelerated, severely impacting patients' quality of life and life expectancy [6]. Studies have shown that compared to patients in plain areas, those with PH in high-altitude areas experience earlier symptom onset, more frequent acute exacerbations, and a more pronounced decline in quality of life [7]. As the largest city on the Qinghai-Tibet Plateau and a key gateway to the region, Xining, the capital of Qinghai Province, is situated at an altitude of approximately 2261 meters [8], and its healthcare system manages a substantial burden of PH cases.

Pulmonary rehabilitation (PR), as an evidence-based comprehensive intervention strategy encompassing exercise training, health education, and psychological and nutritional support, has been established as a cornerstone for improving the functional status of patients with chronic respiratory diseases [9, 10]. However, current PR guidelines are predominantly developed based on populations in plain areas. Parameters such as exercise intensity, safety thresholds, and oxygen therapy indications pose unique challenges when applied in high-altitude hypoxic environments, and direct application may increase rehabilitation risks. When coupled with the uneven distribution of medical resources and the shortage of rehabilitation professionals in high-altitude areas, this may lead to significant disparities in rehabilitation outcomes. To date, research on PR for patients with PH in high-altitude areas remains limited, and there is a lack of a systematic and standardized PR guidance program that integrates multidimensional approaches such as exercise training, breathing exercises, and health education.

Therefore, developing a scientifically validated PR program that specifically addresses the unique characteristics of the high-altitude environment is of significant clinical necessity and academic value. Based on this, the present study aims to develop a PR program tailored to patients with PH on China's Qinghai-Tibet Plateau through a literature review and expert consultation for the first time. This will form a standardized intervention model that can be promoted and evaluated, providing crucial technical support for improving clinical prognosis and enhancing the quality of life for these patients.

2 Materials and methods

2.1 Study design

This study employed a modified e-Delphi method to establish expert consensus on a PR program for patients with PH in high-altitude areas. The Delphi technique is a widely used research methodology in health and social sciences for obtaining consensus from a panel of experts and is regarded as a flexible approach for synthesizing individual opinions into group consensus [11–13]. The Delphi method in this study was conducted electronically (e-Delphi), with questionnaires distributed to experts via WeChat and email. The e-Delphi approach enabled participants to complete the questionnaires at a time and location convenient to them, effectively overcoming geographical barriers and enhancing the feasibility of the study and increasing the participation rate [14]. Personal identifying information of participants was used only for research communication and will not be disclosed in any form in the research results to ensure expert confidentiality.

The initial questionnaire was developed based on a literature review and research team discussions. The development of the initial questionnaire involved two preparatory phases: (1) Literature review: A systematic search was conducted in Chinese and English databases to identify existing evidence on PR for patients with PH (Supplementary Materials 1, S1); (2) Group discussions: The research team convened multiple discussion meetings, during which clinical experts from high-altitude areas (Qinghai Province) provided critical insights based on their frontline experience in managing patients with PH in plateau settings. These discussions not only highlighted that several key parameters and indicators differ significantly from those used in low-altitude areas, but also supplemented clinical practice elements that were inadequately covered in the literature. These two preparatory phases formed the basis for the initial item pool of the Delphi survey. The study flow diagram is shown in Fig. 1.

This study was approved by the Ethics Committee of Qinghai Special Hospital of Cardio-Cerebrovascular Diseases (QXYYLL-2024-87) and conducted in accordance with the Declaration of Helsinki. Electronic informed consent was obtained from all experts prior to participation. The reporting of this Delphi study adheres to the Guidance on Conducting and REporting DElphi Studies (CREDES) checklist [15] to ensure the transparency and completeness of the research process.

2.2 Expert participants

2.2.1 Expert selection criteria

A purposive sampling method was employed to recruit expert panelists for this study. Experts were defined as professionals with substantial knowledge and practical experience in the fields of respiratory diseases or cardiopulmonary rehabilitation, and with in-depth understanding of PR for patients with PH in high-altitude areas. The inclusion criteria for experts were as follows: (1) engagement in work or research related to respiratory diseases or cardiopulmonary rehabilitation; (2) possession of relevant professional certification; (3) bachelor’s degree or higher; (4) intermediate professional title or above; (5) at least 5 years of work experience; (6) provision of informed consent and voluntary participation in the entire Delphi process.

2.2.2 Expert recruitment process

Experts were recruited through the professional networks of the research team members. The research team initially identified and invited potential experts who met the inclusion criteria through professional contacts within their institutions. Snowball sampling was also employed in this study: experts who agreed to participate were invited to recommend other colleagues within their professional networks who met the inclusion criteria and might have valuable insights on the research topic. All recommended experts received an invitation email containing information about the study purpose, methods, expected time commitment, and confidentiality assurances. According to Grime et al. [16], a panel of 5–20 experts is considered most appropriate for the Delphi method. To balance the representativeness and manageability of the expert panel, this study aimed to recruit 15–20 experts to participate in the entire consultation process. Written informed consent was obtained from all participating experts prior to their involvement in the Delphi process. All experts were informed of the study purpose, methods, voluntary nature of participation, and their right to withdraw at any time without consequence.

2.3 Data collection

2.3.1 Questionnaire design

The expert consultation questionnaire was developed in Word document. The questionnaire consisted of four parts: (1) Introduction (study purpose, significance, target population, and instructions for completion); (2) Expert background information (age, gender, professional title, years of work experience, educational background, postgraduate supervisor status, department, and region); (3) Main body (importance and feasibility ratings for each item); (4) Expert familiarity and judgment criteria.

2.3.2 First round of Delphi consultation

In October 2025, the first-round questionnaire (Word document) was sent via WeChat or email to 17 selected experts, along with an explanation of the study. Experts were asked to rate the importance and feasibility of each item based on their professional judgment using a 5-point Likert scale (1 = “not important/feasible”, 5 = “very important/feasible”). Open text boxes were provided at the end of each section for experts to suggest modifications, propose additional statements, or request clarification on item wording. Experts returned the completed documents via WeChat or email. Experts were given two weeks to complete the questionnaire, with reminders sent via WeChat or email if no response was received by the deadline. After the first round, the research team collated the data, calculated the mean score, full-mark percentage, and coefficient of variation (CV) for each item, and summarized the modification suggestions and newly proposed items from the open text boxes. Through group discussion, items were revised, merged, or added based on expert feedback.

2.3.3 Second round of Delphi consultation

Approximately one month after the first round, the second round of Delphi consultation was conducted in December 2025. The second-round questionnaire consisted of items that had reached consensus in the first round (with wording revised based on expert feedback), along with newly added items suggested by experts. Items that did not reach consensus in the first round, as well as those explicitly

recommended for removal by experts, were excluded. The introduction section of the second-round questionnaire provided experts with feedback on the modifications made, to inform their responses in the second round. The rating scale was identical to the first round, and open text boxes were again provided for further suggestions. Experts were given two weeks to complete the second-round questionnaire, with reminders sent via WeChat or email if no response was received by the deadline. After the second round, the research team again collated the data and performed statistical analysis.

2.4 Data collation and analysis

After each round of consultation, the research team collated and analyzed the collected data. Data were entered using Excel 2021 and analyzed using SPSS version 26.0. Descriptive statistics were used to analyze expert demographic characteristics. The expert authority coefficient (Cr) was calculated based on the judgment criteria (Ca) and familiarity (Cs) of experts regarding the questionnaire content, using the formula Cr = (Ca + Cs)/2. The expert positive coefficient was represented by the effective questionnaire response rate. The mean score and full mark ratio were used to indicate the degree of consensus on each item. The CV and Kendall's coefficient of concordance (Kendall's W) were used to assess the degree of coordination among expert opinions, with significance tests performed (with $P < 0.05$ considered statistically significant).

The consensus criteria were established prior to the commencement of the Delphi process. Based on relevant literature [17–19], consensus was defined as meeting all of the following conditions simultaneously: (1) mean score > 3.5; (2) full-mark percentage > 20%; (3) CV < 0.25. Items meeting all three criteria were considered to have reached consensus and were included in the final program. Items that did not fully meet these criteria were discussed by the research team to decide whether to modify them for the next round or delete them.

Modification suggestions, supplementary comments, and requests for clarification on item wording provided by experts in the open text boxes of each round were independently collated by two researchers and entered into a table. The comments were categorized and summarized based on content similarity. The categorized qualitative feedback was submitted to the research team for discussion, and corresponding items were revised, merged, added, or deleted based on the discussion outcomes. After each round, the research team documented the responses to expert comments and the corresponding actions taken (e.g., wording adjustments, addition of new items) to ensure that expert opinions were fully respected and reflected.

3 Results

3.1 Expert characteristics and authority coefficient

A total of 17 experts were invited to participate in two rounds of Delphi consultation, including respiratory physicians, cardiovascular physicians, rehabilitation therapists, and nursing staff. Among them, 14 experts (82.35%) were from high-altitude areas (Qinghai and Tibet). All were frontline clinical

professionals with extensive experience in high-altitude areas, and they possessed in-depth understanding and extensive practical experience in the diagnosis, treatment, and rehabilitation of patients with PH in plateau environments. In addition, three experts from non-high-altitude areas (Shaanxi and Gansu) were invited to provide reference opinions from a non-plateau perspective, thereby enhancing the generalizability and scientific validity of the program. Detailed information on the expert characteristics is presented in Table 1.

Table 1
Demographic and professional characteristics of expert panelists (N = 17)

Characteristic	Frequency	Percentage (%)
Sex		
Male	7	41.18
Female	10	58.82
Age (years)		
30–39	5	29.41
40–49	10	58.82
≥ 50	2	11.76
Professional title		
Chief physician	4	23.53
Associate chief physician	6	35.29
Associate chief nurse	5	29.41
Supervisor therapist	2	11.76
Years of work experience		
5–10	1	5.88
11–20	9	52.94
>20	7	41.18
Educational background		
Bachelor’s degree	12	70.59
Master’s degree	3	17.65
Doctoral degree	2	11.76
Postgraduate supervisor		
Yes	4	23.53
No	13	76.47
Department		
Respiratory medicine	8	47.06
Rehabilitation medicine	5	29.41

Characteristic	Frequency	Percentage (%)
Nursing department	2	11.76
Cardiovascular medicine	1	5.88
Cardiovascular surgery	1	5.88
Region		
Qinghai	9	52.94
Tibet	5	29.41
Shaanxi	2	11.76
Gansu	1	5.88

The expert authority coefficient in this study was 0.835, with a judgment coefficient of 0.95 and a familiarity coefficient of 0.72, indicating that the participating experts possessed a high level of authority. The assignment of judgment criteria and familiarity scores, along with their frequencies, is presented in Tables 2 and 3.

Table 2
Assignment of judgment criteria and frequencies

Judgment criteria	Degree of Influence		
	Large	Medium	Small
Practical experience	0.5(14)	0.4(3)	0.3(0)
Theoretical analysis	0.3(12)	0.2(5)	0.1(0)
Reference to literature	0.1(3)	0.1(12)	0.1(2)
Subjective judgment	0.1(3)	0.1(7)	0.1(7)

Table 3
Assignment of familiarity levels and frequencies

Familiarity level	Very familiar	Familiar	Generally familiar	Unfamiliar	Very unfamiliar
Self-assessment	0.9(4)	0.7(11)	0.5(2)	0.3(0)	0.1(0)

3.2 First round of Delphi consultation

3.2.1 Expert positive coefficient and degree of coordination

In the first round of Delphi consultation, 17 questionnaires were distributed and 17 valid questionnaires were returned, yielding an effective response rate of 100%. Among these, 7 experts (41.18%) provided

modification suggestions, indicating a high level of participation enthusiasm.

Regarding the degree of expert consensus and coordination, the mean importance scores of items ranged from 4.12 to 5.00, with full-mark percentage ranging from 23.53% to 100% and CV ranging from 0 to 0.23. The mean feasibility scores ranged from 3.53 to 4.71, with full-mark percentage ranging from 23.53% to 76.47% and CV ranging from 0.11 to 0.31. Kendall's W for importance and feasibility is presented in Table 4. The distribution of item scores in the first round was presented in Fig. 2, the mean importance scores of items ranged from 4.12 to 5.0, while the mean feasibility scores showed a wider distribution, ranging from 3.53 to 4.71, indicating greater divergence among experts regarding feasibility. Regarding the coefficient of variation, items with CV values approaching or exceeding the consensus threshold of 0.25 were predominantly concentrated in the feasibility dimension. These items spanned multiple domains, including extended team composition, specialized assessments, detailed nutritional guidance, psychological support, and follow-up management.

Table 4
Degree of expert coordination across two Delphi rounds

Round	Item	Importance			Feasibility		
		W	χ^2	P	W	χ^2	P
First round	First-Level Item	0.197	16.749	0.005	0.199	16.936	0.005
	Second-Level Item	0.172	64.455	< 0.001	0.121	45.369	0.002
	Third-Level Item	0.202	209.136	< 0.001	0.198	204.978	< 0.001
	Total	0.199	303.734	< 0.001	0.173	264.144	< 0.001
Second round	First-Level Item	0.337	25.261	< 0.001	0.260	19.487	0.002
	Second-Level Item	0.181	67.833	< 0.001	0.195	72.993	< 0.001
	Third-Level Item	0.217	175.611	< 0.001	0.200	161.659	< 0.001
	Total	0.221	285.643	<0.001	0.197	254.134	<0.001

3.2.2 Item consensus and revisions

The first-round questionnaire comprised 6 first-level items, 23 second-level items, and 62 third-level items (Supplementary Material 1, S2). According to the pre-defined consensus criteria (mean importance score > 3.5, mean feasibility score > 3.5, full mark percentage > 20%, CV < 0.25), two third-level items had CV for feasibility of 0.31 and 0.30, respectively, both exceeding 0.25 and thus failing to reach consensus. These two items were "5.2.1 Encourage patients to record daily activities and emotions, with healthcare

providers and patients reviewing together to reinforce positive behaviors and identify and improve avoidance behaviors” and”5.2.3 Help patients develop objective and rational cognition of the disease and identify automatic thoughts related to the disease”. Both items had feasibility CV values of 0.31 and 0.30, respectively, exceeding the pre-defined threshold of 0.25, indicating a lack of consensus among experts regarding their operability. Consequently, these two items were deleted after group discussion.

A total of 17 modification suggestions were received from 7 experts in the first round. The research team collated, categorized, and discussed each suggestion. Among them, 12 suggestions were fully adopted, 3 were partially adopted, and 2 were not adopted after discussion. Based on the discussion outcomes, corresponding items were revised, merged, added, or deleted. The main expert opinions and revision results are presented in Supplementary Material 1, S3. The revised items were carried forward to the second round (Supplementary Material 1, S4).

3.3 Second round of Delphi consultation

3.3.1 Expert positive coefficient and degree of coordination

In the second round of Delphi consultation, 17 questionnaires were distributed and 15 valid questionnaires were returned, yielding an effective response rate of 88.24%. Among these, 4 experts (26.67%) provided modification suggestions.

Regarding the degree of expert consensus and coordination, the mean importance scores of items ranged from 4.13 to 5.00, with full-mark percentage ranging from 33.33% to 100% and CV ranging from 0 to 0.21. The mean feasibility scores ranged from 3.87 to 4.67, with full-mark percentage ranging from 26.67% to 73.33% and CV ranging from 0.10 to 0.24. Kendall’s W for importance and feasibility is presented in Table 4. These results indicate that after one round of feedback and revision, the degree of expert coordination further improved. The distribution of item scores in the second round was presented in Fig. 3. Compared with the first round, Fig. 3 shows a notable narrowing of the CV distribution across items. The proportion of items with relatively higher CV values decreased substantially, and no item exceeded the consensus threshold of 0.25. The mean feasibility scores shifted upward and became more concentrated, with all items scoring above 3.80. These improvements indicate that expert opinions converged after one round of feedback and revision, particularly for items that initially showed higher variability, such as those related to altitude adjustments and certain psychological support strategies.

3.3.2 Item consensus and revisions

The second-round questionnaire comprised 6 first-level items, 26 second-level items, and 55 third-level items. According to the pre-defined consensus criteria (mean importance score > 3.5, mean feasibility score > 3.5, full mark ratio > 20%, CV < 0.25), all items reached consensus in the second round, indicating a high level of agreement among experts regarding the importance and feasibility of each item.

A total of 9 modification suggestions were received from 4 experts in the second round. The research team collated, categorized, and discussed each suggestion. Among them, 5 suggestions were fully adopted, and 4 were not adopted after discussion. The main expert opinions and revision results are presented in Supplementary Material 1, S5. Notably, one expert suggested “The rehabilitation program should include a ‘rehabilitation goal’ dimension. With assessment and prescription in place, clear rehabilitation goals should also be established.” The research team considered this opinion to have important clinical significance, as it would enhance the guidance and evaluability of the rehabilitation program. After thorough discussion, the research team reached a consensus to adopt this suggestion. Accordingly, a new second-level item “6.4 Dynamic management of rehabilitation goals” was added under the “Follow-up Management” domain, along with two corresponding third-level items (6.4.1 and 6.4.2). Given that all other items had reached consensus in the second round and this addition was based on team consensus following an expert recommendation, a third round of consultation was not conducted.

3.4 Final PR Program

After two rounds of Delphi consultation, the final PR program for patients with PH in high-altitude areas was established. The overall framework of the program was presented in Fig. 4. The number of items within each domain was summarized in Table 5, and the complete list of all items was available in Supplementary Material 2.

Table 5
Number of items in each domain of the final PR program

Dimension	First-Level Item	Second-Level Item	Third-Level Item
Multidisciplinary Team	1	3	10
Rehabilitation Assessment	1	3	5
Exercise Prescription	1	8	14
Health Education	1	6	15
Psychosocial Support	1	3	5
Follow-up Management	1	4	8
Total	6	27	57

4. Discussion

4.1 Necessity of a PR program for patients with PH in high-altitude areas

High-altitude areas, characterized by low atmospheric oxygen partial pressure, are key contributors to the pathogenesis of PH. Studies have shown that residents of high-altitude areas have significantly

higher pulmonary arterial pressure compared to those in plain areas. One study comparing residents living at 2500–3500 meters with age-matched residents living below 800 meters demonstrated that the systolic pulmonary arterial pressure of high-altitude residents was 30 ± 10 mmHg, significantly higher than the 23 ± 5 mmHg observed in low-altitude residents [20]. The underlying mechanism involves hypoxia activating pulmonary vascular endothelial cells and promoting the release of vasoconstrictive factors, thereby accelerating pulmonary vascular remodeling and ultimately leading to the development and progression of PH [21–23]. PR, as a comprehensive intervention strategy, has been widely proven effective in improving exercise tolerance, quality of life, and psychological status in patients with chronic respiratory diseases and some cardiovascular diseases [24, 25].

However, current PR programs are predominantly developed based on physiological parameters and clinical experience from plain areas, failing to adequately incorporate the special effects of high-altitude hypoxic environments on exercise physiology, cardiopulmonary function, and rehabilitation tolerance. Implementing traditional rehabilitation programs in high-altitude environments may increase the risk of exercise-related adverse events due to insufficient consideration of patients' oxygenation status, hemodynamic responses, and exercise safety thresholds under hypoxic conditions, potentially even leading to disease exacerbation [26]. Furthermore, high-altitude areas often face practical challenges such as uneven distribution of medical resources, shortage of rehabilitation professionals, and inadequate rehabilitation facilities, lacking systematic and structured rehabilitation services for patients in these areas [27, 28]. Research on PR specifically for patients with PH in high-altitude areas is even more limited. Therefore, developing a PR program that closely integrates the characteristics of high-altitude environments with clinical practice not only helps unify rehabilitation practice standards and enhance the safety and effectiveness of rehabilitation implementation but also provides clear and operable guidance tools for healthcare professionals in high-altitude areas. This holds significant practical necessity and profound clinical value for improving the overall prognosis and long-term quality of life of patients with PH in these areas.

4.2 Scientific validity and reliability of program development

Based on a literature review and recommendations from clinical healthcare professionals, this study formulated an initial program draft through group discussions. After two rounds of Delphi expert consultation, a PR program suitable for patients with PH in high-altitude areas was developed. Experts from high-altitude areas accounted for 82.35% of the consultation panel, covering core departments such as respiratory medicine, rehabilitation medicine, and cardiology, including professionals from clinical medicine, nursing, and rehabilitation fields. This composition ensured the professionalism and regional adaptability of opinions. Experts with associate senior titles or above accounted for 88.24%, and those with more than 10 years of work experience accounted for 94.12%, indicating that the experts possessed rich clinical experience and could provide comprehensive and instructive suggestions for the program. The effective response rates for the two rounds of consultation were 100% and 88.24%, respectively. Generally, a response rate > 70% indicates good expert positivity [29]. In this study, both

rounds of expert consultation had effective response rates exceeding 70%, demonstrating the invited experts' high enthusiasm and active participation. The expert authority coefficient was 0.835, greater than 0.7, indicating that the experts possessed high authority [30, 31]. After two rounds of consultation, Kendall's W for importance and feasibility both increased compared with the first round, and the results were statistically significant ($P < 0.001$). The mean scores for all items were greater than 3.50, CV were less than 0.25, and full-mark percentage was greater than 20%, indicating that expert opinions tended to converge. Therefore, the program developed in this study possesses good scientific validity and reliability and can guide PR for patients with PH in high-altitude areas. Notably, while Kendall's W improved significantly after two rounds, the absolute values remained below 0.3, indicating modest consensus. This reflects the complexity and novelty of the topic rather than undermining the program's reliability. Given the program's breadth (57 items across six domains) and the limited prior evidence for high-altitude-specific parameters, some divergence among experts is expected. This modest consensus level thus highlights directions for future empirical validation.

4.3 Clinical practicality and innovation of the program

This program takes the "multidisciplinary team" as its implementation core, systematically integrating professionals including respiratory physicians, cardiologists, rehabilitation physicians, rehabilitation therapists, and nurses, while clearly defining the roles and responsibilities of patients and their families in the rehabilitation process. This structure ensures the professionalism and continuity of rehabilitation interventions [32], particularly forming a closed loop in the dynamic monitoring and joint management of cardiovascular risks, providing a feasible team collaboration model for implementing standardized and safe PR under the relatively limited medical resource conditions in high-altitude areas. Additionally, the inclusion of extended team members such as nutritionists, psychologists, and traditional Chinese medicine physicians further enhances the program's cultural adaptability and service integration. In rehabilitation assessment, the program integrates disease risk stratification (using ESC/ERS criteria), exercise safety contraindications, and key physiological monitoring thresholds determined through expert consultation consensus, combining oxygen saturation monitoring thresholds with environmental adaptation indicators to construct an assessment framework that balances disease characteristics with high-altitude physiological features. Notably, several key parameters in the final program originated from research team discussions and were subsequently validated through expert consensus. For example, while the initial program draft set a resting SpO_2 criterion of ≥ 80% before exercise (with a lower limit generally not falling below 70%), the specific threshold of 70% was proposed by the research team based on clinical experience in high-altitude settings and the physiological characteristics of patients with PH. This threshold was carried through both Delphi rounds and achieved consensus. The value of the threshold demonstrates integrating frontline clinical insights from high-altitude practitioners with formal expert consensus methodology, addressing a critical gap where existing evidence from plain-area studies provides limited guidance. In exercise prescription, the program's core innovation lies in establishing the principle of exercise intensity setting and adjustment "based on Xining's altitude". Compared with plain-area programs [33, 34], this baseline itself represents an intensity reduction for high-altitude environments. Building on this foundation, the program further provides stepwise reduction

recommendations for exercise intensity and duration, achieving a systematic and scientific adjustment of exercise prescriptions from “plain mode” to “high-altitude mode”, providing a reference tool for implementing individualized, safe, and effective exercise rehabilitation in high-altitude areas. The selection of Xining as the baseline for exercise intensity adjustments warrants justification. Xining was chosen primarily because, as the capital of Qinghai Province and the largest city on the Qinghai-Tibet Plateau, it serves as the regional healthcare hub where the majority of participating experts practice and where most patients with PH receive their initial diagnosis and ongoing care. Altitudes higher than Xining (e.g., Lhasa at 3650 meters) were not selected as the baseline because they represent more extreme hypoxic conditions that affect a smaller proportion of the target population; instead, adjustments for higher altitudes are provided as stepwise modifications relative to the Xining baseline. Health education encompasses comprehensive coverage from disease management to lifestyle guidance, with stratified and multi-channel implementation methods designed to ensure feasible guidance for patients with different educational levels and living environments. In psychological support, the program integrates positive motivation, peer education, family support, and professional psychological intervention, forming a multi-level psychological intervention system that embodies the holistic rehabilitation medical philosophy [35, 36]. Follow-up evaluation adopts a flexible design combining “mandatory and optional items” and “hospital-community-online follow-up linkage”. This framework ensures standardized monitoring of rehabilitation quality through core indicators (e.g., 6-minute walking distance, symptoms, basic vital signs), while adapting to the practical difficulties of vast geographical areas, uneven medical resources, and inconvenient patient travel in high-altitude areas through optional items and diverse follow-up methods, ensuring long-term feasibility and compliance of rehabilitation management.

Strengths and limitations

This study is the first to construct a PR program for patients with PH in the special environment of high-altitude areas. The program content breaks through the limitations of traditional PR programs centered on plain environments, proposing for the first time the principle of exercise intensity setting “based on Xining’s altitude” and establishing a stepwise adjustment strategy, achieving a scientific transformation from general plain models to high-adaptability plateau models. Secondly, the program clarifies safety thresholds for key indicators such as blood oxygen saturation during exercise in high-altitude environments, enhancing the risk controllability of rehabilitation implementation. Furthermore, it innovatively designs a “hospital-community-online” follow-up mechanism and a “mandatory + optional” flexible assessment system, effectively addressing the practical challenges of uneven medical resources and difficult patient follow-up in high-altitude areas. Finally, the program integrates multidisciplinary team collaboration, reflecting the expansion and application of the holistic rehabilitation concept in special high-altitude populations.

The limitations of this study include the following aspects: First, some innovative content in the program (e.g., altitude gradient adjustments) is primarily based on group discussions and expert consultation consensus and has not yet been validated through clinical empirical research. Its accuracy, safety, and effects on patient function and quality of life require further validation through prospective studies.

Second, one item was added in the second round based on an expert suggestion and subsequent team consensus, rather than through a formal iterative rating process. Although this approach aligns with common qualitative feedback practices in Delphi studies, it represents a minor methodological deviation from purely quantitative consensus procedures. Additionally, the living habits and cultural backgrounds of patients from different ethnic groups in high-altitude areas are diverse, and the program's cultural adaptability and individualized implementation may require further optimization and adjustment. Finally, the translation of the program into widespread clinical practice may face practical challenges such as shortages of professional rehabilitation personnel, difficulty in patient education, and inadequate long-term follow-up systems in high-altitude areas.

5 Conclusion

Through two rounds of Delphi expert consultation, this study developed a PR program suitable for patients with PH in China's Qinghai-Tibet Plateau. The program encompasses six domains: multidisciplinary team, rehabilitation assessment, exercise prescription, health education, psychological support, and follow-up evaluation. The program content is systematic and scientific, possessing both environmental adaptability and clinical operability, providing a key reference framework for implementing PR in high-altitude areas. Future research should focus on clinical validation and effectiveness evaluation of the program, further exploring its applicability and promotion value in real-world healthcare settings.

Declarations

Conflict of interest statement

The authors declare no conflicts of interest.

Ethics approval

This study was approved by the Institutional Review Board (IRB) / Ethics Committee of Qinghai Special Hospital of Cardio-Cerebrovascular Diseases (Approval number: QXYYLL-2024-87). All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent to participate

Electronic informed consent was obtained from all experts prior to participation in the Delphi survey. Participation was voluntary, and questionnaires were distributed only after the experts had agreed to participate.

Clinical trial number

Not applicable.

Consent to Publish declaration

Not applicable.

Author contribution declaration

Wenrui Li and Minwei Chen conceived and designed the study. Xiuying Li, Lei Zhao, Rui Jin, Haiyu Zhao, Jinpeng Ma, Xiangqun Ke, Zhenfeng Zhao, Xiaozhou Wang and Yaping Zeng performed data collection. Wenrui Li and Men Fan analyzed the data and prepared the figures. Wenrui Li, Men Fan and Minwei Chen write the main manuscript text. Minwei Chen supervised the research. All authors reviewed and approved the final manuscript.

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Author Contribution

Wenrui Li and Minwei Chen conceived and designed the study. Xiuying Li, Lei Zhao, Rui Jin, Haiyu Zhao, Jinpeng Ma, Xiangqun Ke, Zhenfeng Zhao, Xiaozhou Wang and Yaping Zeng performed data collection. Wenrui Li and Men Fan analyzed the data and prepared the figures. Wenrui Li, Men Fan and Minwei Chen write the main manuscript text. Minwei Chen supervised the research. All authors reviewed and approved the final manuscript.

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Data Availability

The data can be obtained from the corresponding author upon reasonable request.

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Figures

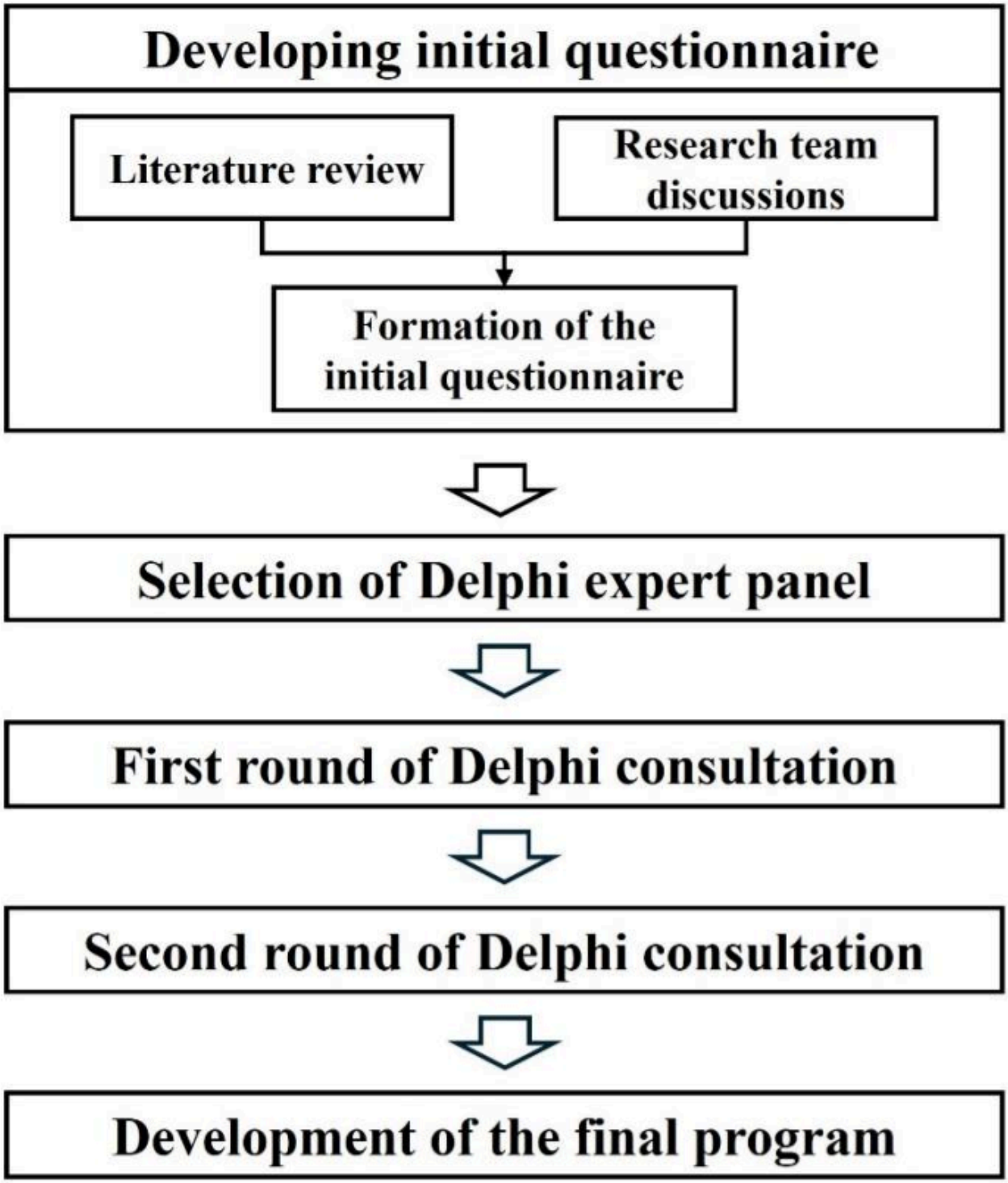


Figure 1

The schematic study flow diagram.

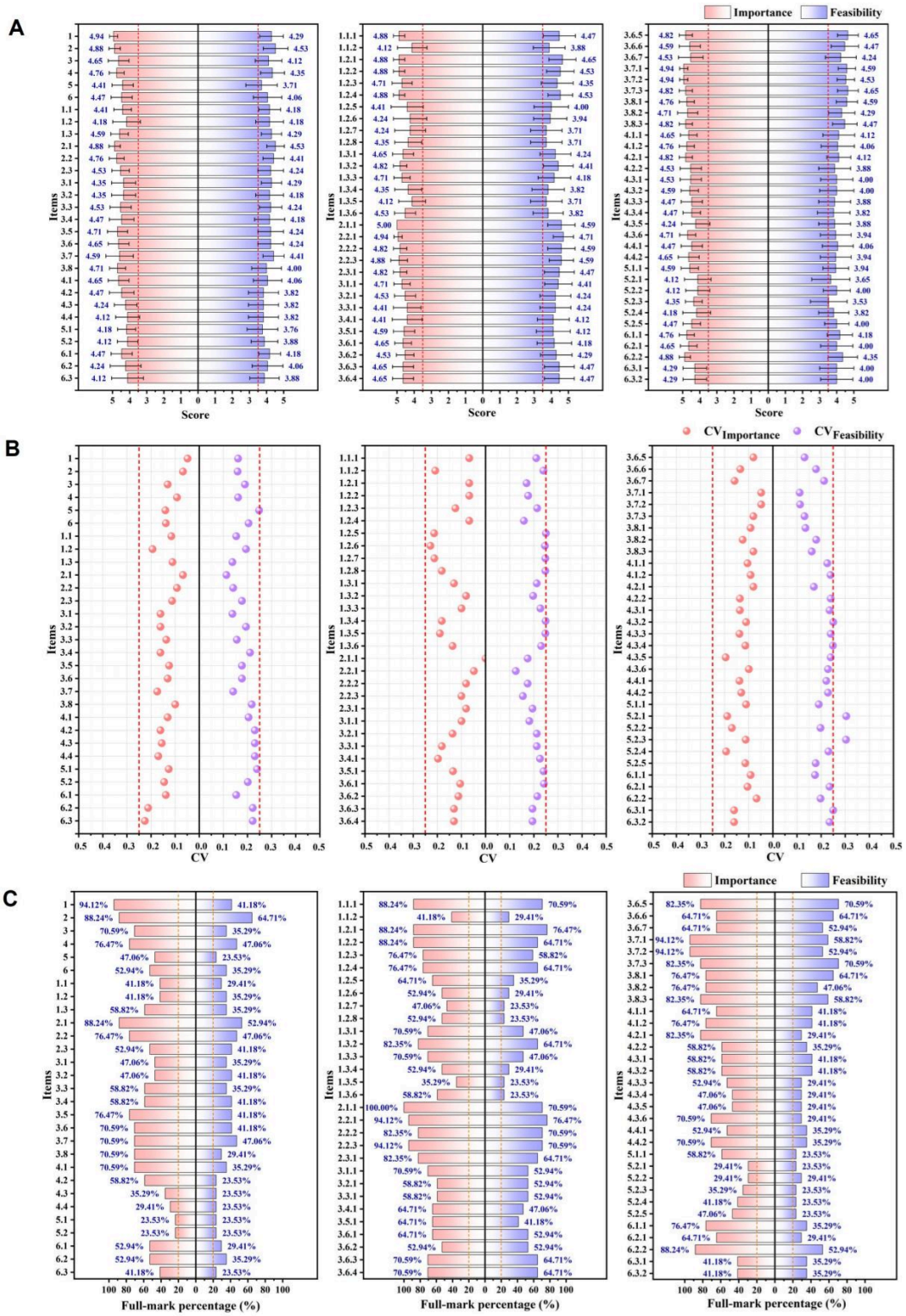


Figure 2

The distribution of item scores in the first round of Delphi consultation. (A) Mean scores with SD (error bars)；(B) CV; (C) Full-mark percentage.

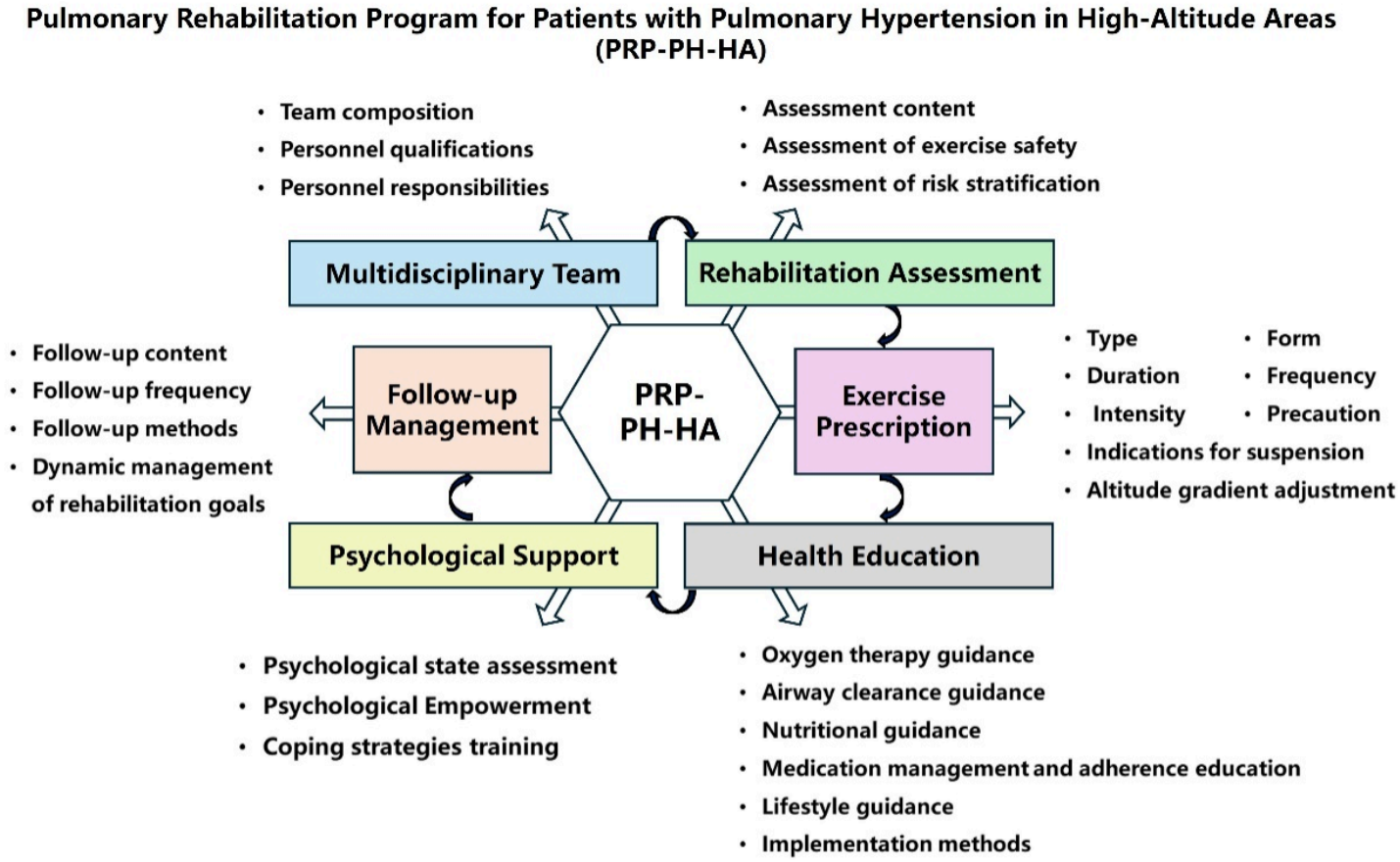


Figure 3

Framework of the pulmonary rehabilitation program for patients with pulmonary hypertension in high-altitude areas

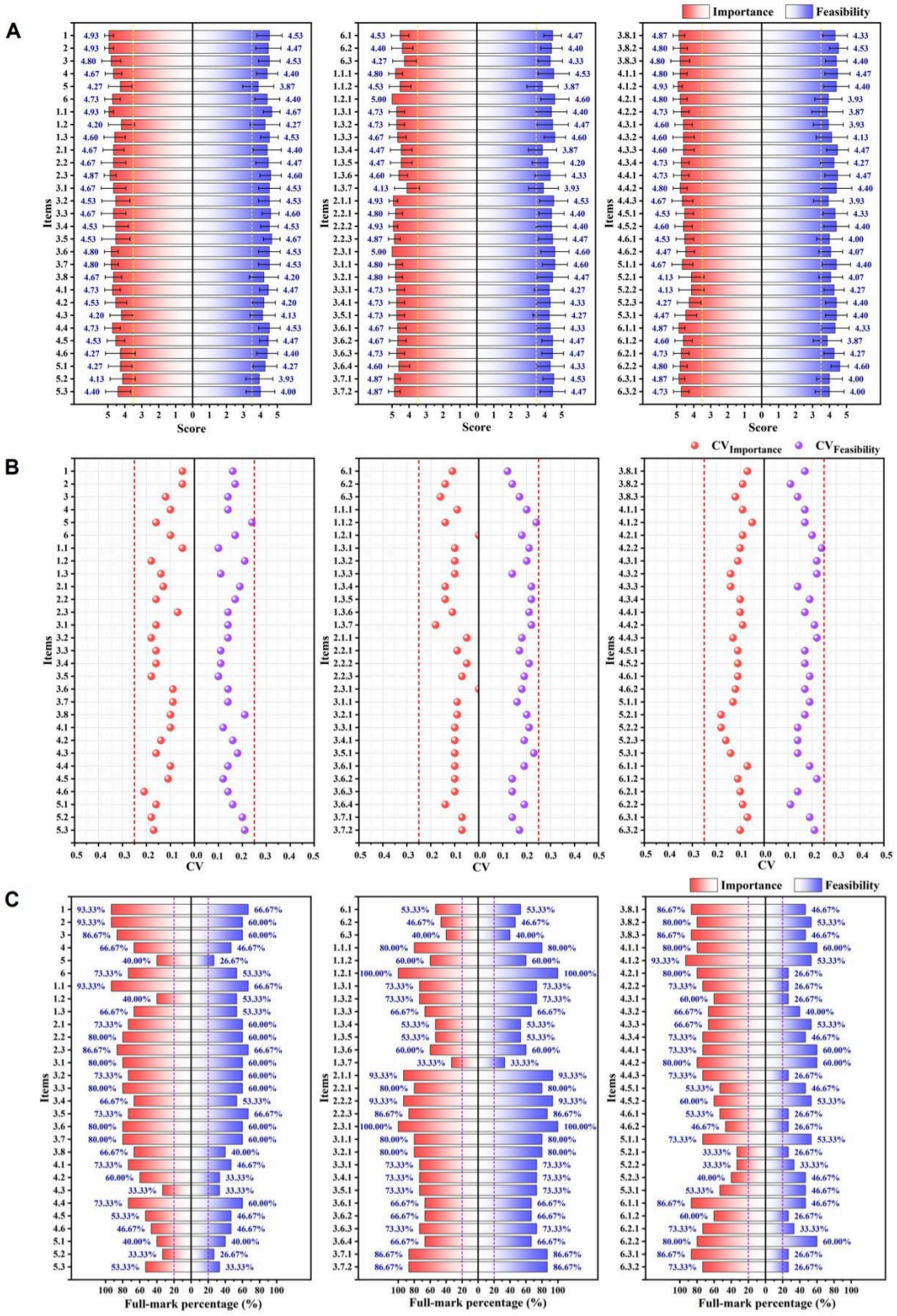


Figure 4

The distribution of item scores in the second round of Delphi consultation. (A) Mean scores with SD (error bars); (B) CV; (C) Full-mark percentage.

Supplementary Files

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