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Ultrasound-guided high-voltage vs conventional pulsed radiofrequency in elderly cervical radiculopathy: A randomized controlled trial

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Abstract: **Background**: Elderly patients with cervical radiculopathy present therapeutic challenges owing to comorbidities and medication-related risks. Long-term pharmacotherapy and surgical interventions are often suboptimal, necessitating evaluation of optimized pulsed radiofrequency strategies under image guidance. **Objectives**: This superiority trial compared the efficacy and safety of ultrasound-guided cervical nerve root high-voltage pulsed radiofrequency (HVP-PRF) versus conventional pulsed radiofrequency (C-PRF) for pain management in elderly patients with cervical radiculopathy. **Methods**: This single-center, parallel-group, assessor-blinded randomized controlled trial enrolled patients aged 60–85 years with cervical radiculopathy, randomly assigned (1:1) to HVP-PRF (70 V) or C-PRF (45 V). Procedures were performed under ultrasound guidance with sensory/motor stimulation confirmation and temperature ≤42°C. The primary outcome was change in upper-limb radiating pain on the Numeric Rating Scale (ΔNRS) from baseline to 3 months. Secondary outcomes included Neck Disability Index (NDI), neck pain NRS, Patient Global Impression of Change, responder rates, rescue analgesia use, and adverse events. Follow-up occurred at 1 week, 1, and 3 months. **Results**: A total of 104 patients were randomized and 101 received treatment. At 3 months, HVP-PRF demonstrated significantly greater radiating pain improvement versus C-PRF (adjusted mean difference 1.24, 95% CI 0.46–2.02, P=0.002). Functional improvement (NDI) was superior in the HVP-PRF group at 3 months (AMD 6.47, 95% CI 2.11–10.83, P=0.004). Responder rates (≥50% pain reduction) were higher with HVP-PRF at 3 months (68.75% vs. 42.22%, OR 3.01, P=0.011) and 6 months (65.22% vs. 43.18%, OR 2.52, P=0.035). Rescue analgesic use was lower in the HVP-PRF group during 1–3 months intervals (both P<0.05). Adverse event rates were comparable (27.45% vs. 32.00%). **Conclusion**: Under ultrasound visualization and electrical stimulation-based target confirmation with temperature control ≤42°C, HVP-PRF provided greater and more durable relief of upper limb radiating pain compared with C-PRF in elderly patients with cervical radiculopathy, with a comparable safety profile.

Keywords: Cervical radiculopathy; Elderly; Pulsed radiofrequency; Randomized controlled trial; Ultrasound-guided

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INTRODUCTION

Cervical radiculopathy is a common condition in the aging population, with prevalence increasing as degenerative changes of the cervical spine progress (Luyao *et al.*, 2022). Intervertebral disc herniation, osteophyte formation and ligamentum flavum hypertrophy can lead to intervertebral foraminal stenosis, resulting in nerve root compression, ischemia and inflammatory responses that manifest as radiating pain with neuropathic components (Kim *et al.*, 2023, Mansfield *et al.*, 2020). Patients often present with neck and shoulder pain accompanied by upper limb radiating pain, numbness, or sensory abnormalities; the pain is consistent with dermatomal distribution, affecting gripping, dressing, and sleep, and severe cases develop decreased muscle strength, limiting daily activities and increasing the risk of recurrence (Peene *et al.*, 2023). Elderly patients with cervical radiculopathy represent a particularly challenging subgroup with limited therapeutic options (Pan *et al.*, 2024). Surgical intervention in this population carries heightened risks due to comorbidities, reduced physiological reserve and age-related anatomical changes, while prolonged medication use increases the risk of gastrointestinal bleeding, renal dysfunction, cognitive impairment and fall-related injuries (By the American Geriatrics Society Beers Criteria Update Expert, 2019). Conservative treatments often provide insufficient relief and epidural steroid injections raise concerns about blood glucose fluctuations and osteoporosis exacerbation (Lee *et al*., 2021). These considerations create a clinical gap for minimally invasive, steroid-free interventions that are repeatable and safe in the aging population, a gap that pulsed radiofrequency may fill. However, the specific efficacy and safety of PRF in elderly patients remain insufficiently characterized, particularly regarding parameter optimization. This trial directly addresses this evidence gap by focusing exclusively on patients aged ≥60 years with well-defined cervical radiculopathy. Pulsed radiofrequency delivers pulsed current under an upper

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temperature limit, reducing abnormal discharges via electric field-related neuromodulation and has been used for radicular pain at multiple sites (Lee & Moon, 2021). Selective nerve root blocks or epidural injections can provide short-term relief, but efficacy is variable and the use of glucocorticoids raises concerns about blood glucose fluctuations and osteoporosis in elderly patients, highlighting the need for steroid-free neuromodulation strategies (Murata *et al.*, 2020).

Accurate localization is particularly critical in cervical interventions, where the nerve roots are in close proximity to the vertebral artery and dural sac (Wang *et al.*, 2024). Various imaging modalities are available for guidance: fluoroscopy provides bony landmark reference but lacks soft-tissue visualization and carries radiation exposure; CT offers superior anatomical detail but is resource-intensive and exposes patients to higher radiation doses; ultrasound uniquely provides real-time visualization of nerves, vessels and adjacent structures without radiation, with color Doppler enabling identification and avoidance of the vertebral artery and other vascular structures (Jecklin *et al.*, 2025). When combined with sensory and motor stimulation for physiological confirmation, ultrasound-guided techniques achieve reliable target identification. While ultrasound is operator-dependent and has a learning curve, its practical advantages, particularly for elderly patients who may have difficulty maintaining positioning, made it the preferred modality for this study. Previous studies on voltage optimization have yielded conflicting results, largely due to heterogeneous parameters and small sample sizes; high-quality randomized evidence specifically addressing high-voltage PRF in the elderly population remains limited (Langford *et al.*, 2023).

Therefore, this superiority trial was designed to compare cervical nerve root high-voltage pulsed radiofrequency (HVP-PRF) with conventional pulsed radiofrequency (C-PRF) under ultrasound visualization and electrical stimulation confirmation. It was hypothesized that HVP-PRF would provide superior pain relief compared with C-PRF at 3 months post-treatment, without increasing adverse events.

MATERIALS AND METHODS

Study design

This was a single-center, parallel-group, randomized controlled, assessor-blinded superiority trial conducted in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines. The study compared the efficacy and safety of ultrasound-guided cervical nerve root high-voltage pulsed radiofrequency (HVP-PRF) versus conventional pulsed radiofrequency (C-PRF) for treating pain in elderly patients with cervical radiculopathy. The study was completed in the Department of Pain Medicine at the First People's Hospital of Jiashan County. The recruitment period was from June 1, 2024 to May 31, 2025 and the last participant completed follow-up on November 30, 2025. The study protocol was approved by the hospital ethics committee (approval No. 20240305-08A) and all participants signed written informed consent before enrollment. The trial was registered with the China Clinical Trial Registration Center (Registration Number: ChiCTR2400082698).

Participants and recruitment process

Participants were consecutively screened from the outpatient clinic of the Department of Pain Medicine. Inclusion criteria were: age 60–85 years; meeting diagnostic criteria for cervical radiculopathy with unilateral neck-shoulder-upper limb radiating pain consistent with dermatomal distribution; positive Spurling test or positive upper limb nerve traction test on physical examination; cervical MRI or CT showing intervertebral foraminal stenosis or nerve root compression matching clinical symptoms; pain duration ≥3 months; baseline average upper limb radiating pain Numeric Rating Scale (NRS, 0–10) over the past 24 hours ≥4 (Han *et al.*, 2020); and receipt of standardized conservative treatment for ≥6 weeks with unsatisfactory efficacy.

Exclusion criteria: cervical myelopathy suggested by clinical or imaging findings; progressive upper limb muscle strength decline with muscle strength grade ≤3; cervical instability or severe spinal canal stenosis requiring emergency or planned surgical treatment; history of cervical spine surgery; local cervical infection or systemic infection; tumors, fractures, rheumatic and immune inflammatory diseases of the spine; coagulation disorders or anticoagulant/antiplatelet therapy that could not be discontinued according to perioperative requirements; severe cardiopulmonary insufficiency (American Society of Anesthesiologists classification ≥ class IV); severe cognitive impairment or psychiatric disorders leading to inability to cooperate with assessment; allergy to lidocaine; cervical nerve root radiofrequency treatment or cervical epidural injection treatment within the past 6 months.

After initial outpatient screening, imaging and physical examination were reviewed. Two study physicians who did not participate in the procedures jointly confirmed the consistency of symptoms, signs and imaging findings and determined the target nerve root segment. After baseline assessment completion, participants entered randomization. Participants could withdraw during follow-up due to personal preference; those with serious adverse events or requiring surgical treatment discontinued study treatment but continued to complete safety and outcome follow-up. For participants lost to follow-up, the study team made three telephone contacts and sent one text message reminder within the scheduled follow-up window; those unable to return to the hospital completed NRS, NDI and PGIC assessments by telephone.

Randomization, allocation concealment and blinding

Participants were randomly assigned in a 1:1 ratio to the HVP-PRF group or the C-PRF group. The random sequence was generated by an independent statistician using a computer, using block randomization (block size of 4) and allocation concealment was implemented using sequentially numbered, opaque, sealed envelopes. After completion of the baseline assessment, a study nurse who did not participate in the outcome assessment opened the envelope and instructed the interventional operator to perform the corresponding parameter protocol. Due to differences in intervention parameters, the interventional operator was not blinded; however, outcome assessors and statistical analysts remained blinded to group assignment. The study database was labeled with A/B codes before statistical analysis and unblinding was performed only after completion of the primary analysis. The potential for performance and expectation biases due to the lack of participant blinding is acknowledged as a limitation.

Interventions and procedure

Ultrasound visualization-guided localization and target confirmation

All procedures were performed under sterile conditions by two pain physicians with more than 10 years of experience in ultrasound-guided cervical interventions, using a standardized protocol to minimize inter-operator variability. The ultrasound equipment used a high-frequency linear array probe (6–15 MHz). Radiofrequency treatment used the same model radiofrequency generator and disposable radiofrequency puncture needle (22G, length 100 mm, effective exposed tip 5 mm), with impedance and temperature recorded throughout (Table S1).

Participants were placed in the supine position, with the head turned toward the unaffected side and slightly extended. Ultrasound scanning was performed in the transverse plane at the target segment to clearly display the anterior and posterior tubercles of the corresponding transverse process and the course of the nerve root; color Doppler was used to identify and avoid the vertebral artery and visible vascular structures. An in-plane approach was used and the needle tip was placed in the proximal area adjacent to the target nerve root. Target confirmation was determined by combined electrical stimulation: sensory stimulation at 50 Hz elicited radiating sensation consistent with the participant's main pain, with a threshold ≤0.5 V; motor stimulation at 2 Hz up to 2.0 V did not produce visible upper limb muscle twitching. If the sensory stimulation threshold was not achieved at the initial needle position, minor adjustments were made, with a maximum of two adjustment attempts permitted to avoid prolonged procedure time and patient discomfort. Pulsed radiofrequency treatment was initiated after completion of needle-tip positioning. No glucocorticoids or local anesthetics were injected around the nerve root—a deliberate design choice to isolate the pure neuromodulatory effect of PRF.

High-voltage pulsed radiofrequency group: Parameter settings and procedure steps

The HVP-PRF group used the following fixed parameters: output voltage 70 V. This voltage was selected based on previous dose-finding studies that systematically evaluated multiple voltage levels (50V, 60V, 70V, 80V) and demonstrated that 70V provided optimal analgesic efficacy while remaining within the 42°C safety limit in vivo (Vigneri *et al.*, 2020, Khan *et al.*, 2025). The 80V condition, although showing additional electrophysiological effects, approached the temperature threshold more rapidly and was therefore excluded to maintain a consistent safety margin. Importantly, these voltage parameters were established using the same equipment model and needle type as in the present study, ensuring applicability.

Conventional pulsed radiofrequency group: Parameter settings and procedure steps

The C-PRF group used the following fixed parameters: an output voltage of 45 V, which corresponds to the conventional voltage level most commonly employed in pulsed radiofrequency for cervical radicular pain, as documented in multiple clinical studies and systematic reviews (Waardenburg *et al.*, 2022). This voltage was selected as the comparator to reflect current standard practice.

Perioperative management, concomitant treatment restrictions and rescue analgesia protocol

All participants underwent vital sign assessment before the procedure and intraoperative monitoring included electrocardiography, blood pressure and oxygen saturation. Local infiltration anesthesia of the skin and subcutaneous tissue used 2 mL of 1% lidocaine and no sedative drugs were used. After the procedure, participants were observed in the observation area for 30 minutes and discharged after confirming no progressive neurological dysfunction. During the study period, other invasive cervical pain interventions and cervical spine surgery were prohibited. Physiotherapy and other non-invasive treatments were not standardized but were systematically recorded at each follow-up visit (type, frequency, duration) as potential confounders. These variables were included as covariates in sensitivity analyses to assess their potential influence on treatment effect estimates. Previous long-term analgesic or neuropathic pain medications were allowed to continue, but the dose had to be stable for 2 weeks before randomization and remain unchanged during follow-up; adjustments made for safety reasons were recorded as protocol deviations. Rescue analgesia was uniformly acetaminophen 0.5 g per dose, with a maximum dose of 2.0 g within 24 hours; participants recorded the dose and time of each administration in patient diaries, which were reviewed and collected at each follow-up visit.

Outcome measures and follow-up assessment

All outcomes were assessed by study physicians who did not participate in the interventional procedures at baseline (pre-procedure), 1 week after treatment, 1 month after treatment, 3 months after treatment and 6 months after treatment. The primary outcome was the change in upper limb radiating pain NRS from baseline at 3 months after treatment (ΔNRS, 0–10), with NRS defined as "the average upper limb radiating pain intensity over the past 24 hours" (Waardenburg *et al.*, 2022). Secondary outcomes included: changes in upper limb radiating pain NRS and neck pain NRS at each follow-up time point; changes in the Neck Disability Index (NDI), with NDI being the total score of 10 items (0-50) and converted to a percentage scale (0-100) (Waardenburg *et al.*, 2022); Patient Global Impression of Change (PGIC, a 7-point scale, from "very much improved" to "very much worse") (Ding *et al.*, 2020); responder rates at 3 and 6 months, with responders defined as an upper limb radiating pain NRS decrease ≥50% from baseline at that time point; rescue analgesic use, calculated as the cumulative dose (g) of acetaminophen over each follow-up interval.

Safety monitoring and adverse event management

Safety observation covered the intraoperative period, the immediate post-procedure period, and the entire follow-up period. Prespecified adverse events included: puncture-site bleeding or hematoma; puncture-site infection; vasovagal reflex; pain rebound within 48 hours after the procedure; persistent numbness or sensory abnormalities lasting more than 7 days; new or worsened limb weakness; dysphagia; hoarseness; dizziness; pneumothorax; vascular injury; complications requiring hospitalization; death. Adverse events were actively inquired about by outcome assessors and recorded alongside physical examination; severity was graded according to CTCAE 5.0. Serious adverse events were defined as events resulting in death, life-threatening conditions, requiring hospitalization or prolonged hospitalization, or resulting in persistent or significant disability. The relatedness between events and the intervention was independently adjudicated by two study physicians who did not participate in the procedures; if opinions were inconsistent, a third study physician adjudicated. In cases of progressive neurological deficits, neurology or spine surgery consultation was immediately initiated and the study intervention was terminated, while safety follow-up continued.

Sample size estimation and statistical analysis

The sample size was estimated based on the primary outcome (ΔNRS at 3 months after treatment). The minimum clinically relevant difference between the two groups was set at 1.2 points, the standard deviation at 2.0 points, two-sided $\alpha=0.05$ and power at 80%. According to the formula for the difference in means between two independent samples, 44 participants were required per group; with a 15% dropout rate, 52 participants per group were planned, for a total sample size of 104.

Statistical analysis was primarily based on the intention-to-treat (ITT) population, including all randomized participants; the safety analysis set included all participants who received radiofrequency treatment; and the per-protocol analysis set (PP) included participants who completed the prescribed radiofrequency treatment and had complete 3-month follow-up data without key protocol deviations. Concomitant non-invasive treatments (physiotherapy, exercise and complementary therapies) were recorded and included as time-varying covariates in exploratory sensitivity analyses to assess whether between-group differences in their use could confound the primary efficacy estimates. Continuous variables were described as mean ± standard deviation or median (interquartile range) and categorical variables were described as frequency (percentage). Between-group comparisons of baseline characteristics used an independent-samples t-test or Mann-Whitney U test and categorical variables used chi-square test or Fisher exact test. The primary outcome and the repeated-measures continuous secondary outcomes were analyzed using linear mixed-effects models, with fixed effects including group, time, and the group × time interaction, and the corresponding baseline value of the outcome as a covariate; participants were specified as random intercepts. This approach helps account for unmeasured confounding, including the potential influence of stable baseline medication use. The primary effect was expressed as the adjusted mean difference between groups at 3 months after treatment, along with its 95% confidence interval. Responder rates were compared using binary logistic regression, with the model including group and adjusting for baseline NRS. Cumulative rescue analgesic dose was compared using the Mann-Whitney U test and presented as the median difference and interquartile range. All tests were two-sided and $P<0.05$ was considered statistically significant. No multiple-comparison adjustment was performed for secondary outcomes, and results were interpreted as exploratory. For missing data handling, the linear mixed-effects model used maximum likelihood estimation under the premise that the "missing mechanism satisfies missing at random"; meanwhile, multiple imputation (chained equations, 20 imputations) was performed for the primary outcome as a sensitivity analysis and robustness was verified by comparison with PP analysis results. Statistical analysis was completed using R software (version 4.3.2).

Data management and quality control

All data were recorded on paper CRFs, double-entered independently, and locked for analysis after completion of logic and range checks; identity information was replaced with study numbers, and access was restricted. Before the study, the operating procedures were uniformly trained; during the study, 10% of cases were randomly checked each month to verify key procedure records and ensure follow-up consistency; devices were the same model and were regularly calibrated.

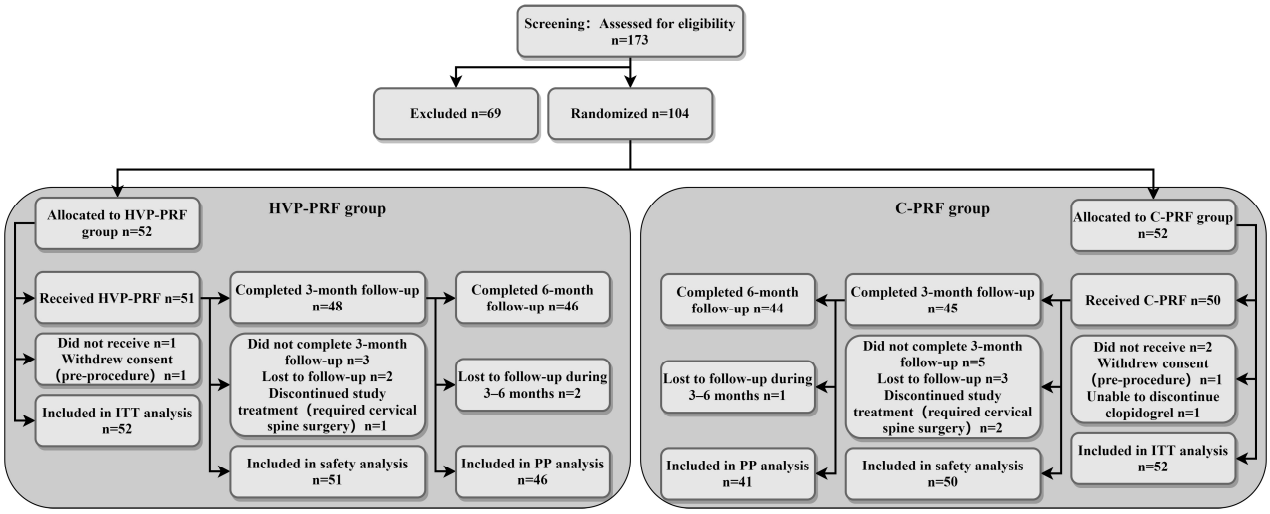

Fig. 1: Participant flow diagram (CONSORT).

Table 1: Baseline demographic and clinical characteristics of the two groups.

Variable	HVP-PRF group (n=52)	C-PRF group (n=52)	P
Age (years)	69.42 ± 6.18	70.11 ± 6.47	0.579
Sex (male)	27 (51.92%)	25 (48.08%)	0.695
Pain duration (months)	9.63 ± 4.28	10.17 ± 4.56	0.535
Affected side (right)	30 (57.69%)	28 (53.85%)	0.693
Baseline upper limb radiating pain NRS (0-10)	6.48 ± 1.18	6.52 ± 1.21	0.865
Baseline neck pain NRS (0-10)	5.21 ± 1.27	5.18 ± 1.33	0.907
Baseline NDI (0-100)	46.73 ± 12.94	47.58 ± 13.21	0.741

Note: Data are presented as ($\bar{x}\pm s$) or n (%). Continuous variables were analyzed using independent-samples t test; categorical variables were analyzed using χ^2 test or Fisher exact test. NRS: numeric rating scale; NDI: Neck Disability Index (0-100).

RESULTS

Participant flow and baseline characteristics

A total of 173 patients were screened in this study. After excluding 69 patients, 104 patients were randomized, with 52 patients each in the HVP-PRF and C-PRF groups, of whom 51 and 50 patients, respectively, actually received treatment. By 3 months after treatment, 48 patients in the HVP-PRF group and 45 in the C-PRF group completed follow-up, and the overall loss-to-follow-up rate was low (Fig 1). There were no statistically significant differences between the two groups in age, sex, pain duration, affected side, baseline upper limb radiating pain NRS, baseline neck pain NRS, and NDI (all $P > 0.05$), indicating comparable baseline characteristics (Table 1).

Treatment implementation and intraoperative records

The distribution of target segments was similar between the two groups; there were no statistically significant differences between groups in intraoperative monitoring indicators, including sensory stimulation threshold, impedance, and maximum needle-tip temperature. Motor stimulation did not induce visible muscle twitching in either group and the maximum needle-tip temperature did not exceed 42°C in either group; the proportions completing the prescribed radiofrequency time were similar (all $P>0.05$) (Table 2).

Primary outcome

The adjusted between-group difference in ΔNRS of upper limb radicular pain did not reach statistical significance at 1 week after treatment. However, from 1 month after treatment, the HVP-PRF group showed superior outcomes compared with the C-PRF group, with the largest difference observed at 3 months after treatment (adjusted mean difference [AMD] 1.24, 95% confidence interval [CI] 0.46–2.02, $P = 0.002$) (Fig 2). This difference exceeds the prespecified minimal clinically important difference of 1.2 points. Sensitivity analyses of the primary outcome were consistent with the primary analysis, with both MI-ITT and PP analyses showing greater improvement in ΔNRS at 3 months after treatment in the HVP-PRF group than in the C-PRF group (AMD 1.19 and 1.33, respectively, both $P < 0.01$), suggesting that the primary conclusion was robust (Table 3).

Table 2: Distribution of interventional target segments and intraoperative monitoring parameters.

Item	HVP-PRF group (n=51)	C-PRF group (n=50)	P
Target nerve root segment distribution			0.962
C5	6 (11.76%)	5 (10.00%)	
C6	20 (39.22%)	18 (36.00%)	
C7	19 (37.25%)	20 (40.00%)	
C8	6 (11.76%)	7 (14.00%)	
Sensory stimulation threshold (50 Hz, V)	0.36 ± 0.08	0.37 ± 0.09	0.556
Motor stimulation safety check (2 Hz, no visible muscle twitching up to 2.0 V)	51 (100.00%)	50 (100.00%)	1.000
Impedance before radiofrequency initiation (Ω)	392.84 ± 63.19	384.17 ± 59.57	0.480
Maximum needle-tip temperature during treatment (°C)	41.66 ± 0.19	41.60 ± 0.21	0.135
Maximum needle-tip temperature >42°C	0	0	1.000
Completed prescribed radiofrequency time (240 s)	48 (94.12%)	49 (98.00%)	0.617

Note: Data are presented as ($\bar{x}$±s) or n (%). Continuous variables were analyzed using independent-samples t test; categorical variables were analyzed using χ^2 test (Fisher exact test when necessary). Based on the safety analysis set (participants who received radiofrequency treatment).

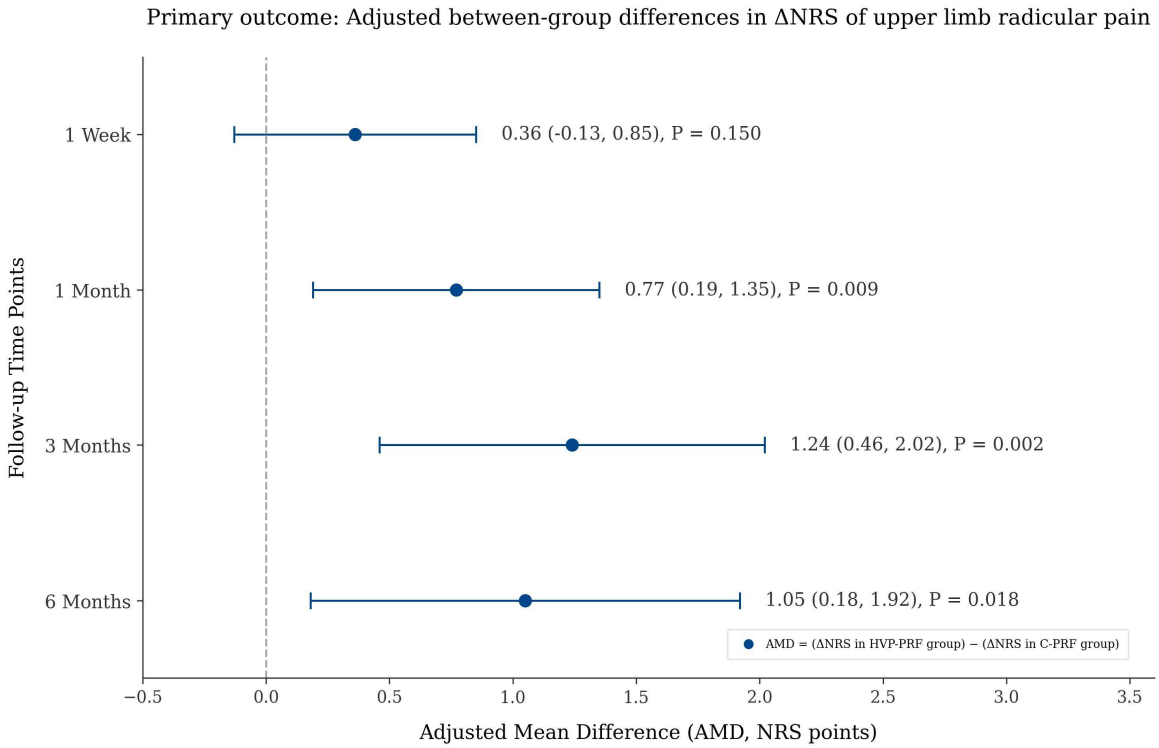

Fig. 2: Primary outcome: Adjusted between-group differences in ΔNRS of upper limb radicular pain. ΔNRS = baseline - follow-up; AMD is the adjusted mean difference of HVP-PRF relative to C-PRF (95%CI), AMD>0 indicates HVP-PRF is superior. Linear mixed-effects model adjusted for baseline NRS (ITT, maximum likelihood).

Table 3: Sensitivity analyses of the primary outcome.

Analysis method	AMD (95% CI) (NRS points)	P
Multiple imputation ITT (MI-ITT)	1.19 (0.41–1.97)	0.003
Per-protocol analysis (PP)	1.33 (0.52–2.14)	0.001

Note: MI-ITT was multiple imputation by chained equations (m=20) and combined according to Rubin rules; both MI-ITT and PP used the same linear mixed-effects model as the primary analysis. ΔNRS = baseline - follow-up; AMD>0 indicates HVP-PRF is superior to C-PRF.

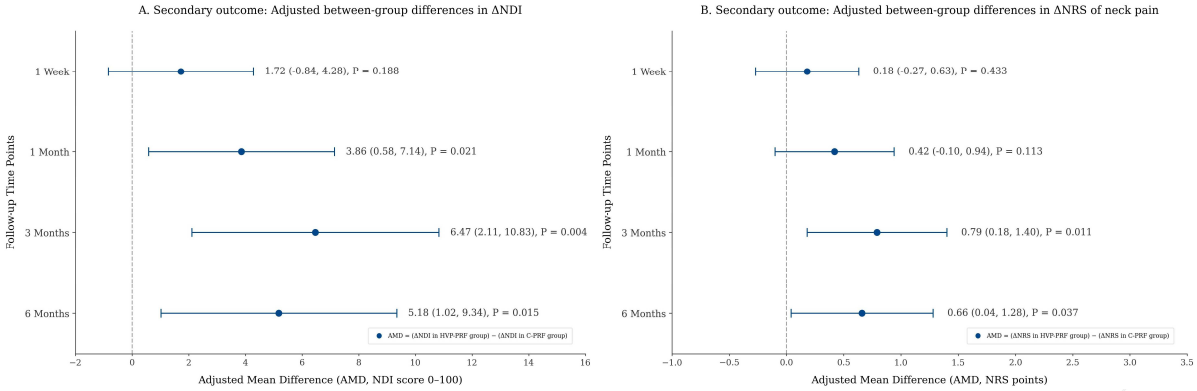

Fig. 3: Secondary outcomes: Adjusted between-group differences in function and neck pain. (A) Adjusted between-group differences in ΔNDI. ΔNDI = baseline – follow-up. AMD indicates adjusted mean difference (HVP-PRF minus C-PRF, 95% CI); AMD > 0 favors HVP-PRF. Linear mixed-effects model adjusted for baseline NDI (ITT analysis, maximum likelihood estimation); (B) Adjusted between-group differences in ΔNRS of neck pain. ΔNRS = baseline – follow-up. AMD indicates adjusted mean difference (HVP-PRF minus C-PRF, 95% CI); AMD > 0 favors HVP-PRF. Linear mixed-effects model adjusted for baseline neck pain NRS (ITT analysis, maximum likelihood estimation).

Table 4: Distribution of PGIC at each follow-up time point.

PGIC grade	1-week HVP-PRF	1 week C-PRF	1-month HVP-PRF	1 month C-PRF	3 months HVP-PRF	3 months C-PRF	6 months HVP-PRF	6 months C-PRF
PGIC 1 (very much improved)	6/51 (11.76%)	4/50 (8.00%)	10/49 (20.41%)	6/48 (12.50%)	15/48 (31.25%)	8/45 (17.78%)	13/46 (28.26%)	7/44 (15.91%)
PGIC 2 (much improved)	15/51 (29.41%)	12/50 (24.00%)	18/49 (36.73%)	14/48 (29.17%)	17/48 (35.42%)	13/45 (28.89%)	16/46 (34.78%)	12/44 (27.27%)
PGIC 3 (minimally improved)	18/51 (35.29%)	18/50 (36.00%)	13/49 (26.53%)	15/48 (31.25%)	10/48 (20.83%)	13/45 (28.89%)	9/46 (19.57%)	12/44 (27.27%)
PGIC 4 (no change)	10/51 (19.61%)	13/50 (26.00%)	7/49 (14.29%)	10/48 (20.83%)	5/48 (10.42%)	9/45 (20.00%)	7/46 (15.22%)	10/44 (22.73%)
PGIC 5 (minimally worse)	2/51 (3.92%)	3/50 (6.00%)	1/49 (2.04%)	3/48 (6.25%)	1/48 (2.08%)	2/45 (4.44%)	1/46 (2.17%)	3/44 (6.82%)
PGIC 1-2 (very much/much improved)	21/51 (41.18%)	16/50 (32.00%)	28/49 (57.14%)	20/48 (41.67%)	32/48 (66.67%)	21/45 (46.67%)	29/46 (63.04%)	19/44 (43.18)

Note: PGIC is a 7-point ordered scale, with smaller scores indicating greater improvement; N is the number of participants with PGIC data at that time point. PGIC grades 6-7 were 0 at all time points and are not listed.

Secondary outcomes

At 1 week after treatment, the between-group difference in NDI improvement did not reach statistical significance; from 1 month after treatment, functional improvement was more pronounced in the HVP-PRF group than in the C-PRF group, with the largest difference at 3 months after treatment (AMD 6.47, 95%CI 2.11–10.83, P=0.004) (Fig 3A). At 1 week and 1 month after treatment, the between-group differences in ΔNRS of neck pain did not reach statistical significance; at 3 months and 6 months after treatment, relief was more pronounced in the HVP-PRF group than in the C-PRF group, with the largest difference at 3 months (AMD 0.79, 95%CI 0.18–1.40, P=0.011) (Fig. 3B). Descriptive PGIC results suggested better overall improvement in the HVP-PRF group: the proportion of PGIC grades 1–2 was higher than that in the C-PRF group at 3 months after treatment (66.67% vs 46.67%) and 6 months after treatment (63.04% vs 43.18%); the proportion of worsening was low and no PGIC grades 6–7 were observed (Table 4). At 3 months and 6 months after treatment, the responder rate in the HVP-PRF group was higher than that in the C-PRF group and the difference remained significant after adjusting for baseline radicular pain NRS, with OR 3.01 at 3 months and OR 2.52 at 6 months (both P<0.05) (Table 5). Rescue analgesic use was similar between the two groups in the early period, whereas from 1 month after treatment the cumulative acetaminophen dose in the HVP-PRF group was lower than that in the C-PRF group and the differences reached statistical significance at 1–3 months and 3–6 months (both P<0.05) (Table 6).

Table 5: Responder rates of ≥50% improvement in upper limb radiating pain at 3 and 6 months after treatment.

Time point	Responders in HVP-PRF group	Responders in C-PRF group	OR (95% CI)	P
3 months after treatment	33/48 (68.75)	19/45 (42.22)	3.01 (1.29–7.05)	0.011
6 months after treatment	30/46 (65.22)	19/44 (43.18)	2.52 (1.07–5.94)	0.035

Note: Responders were defined as an upper limb radiating pain NRS decrease ≥50% from baseline at that time point (baseline - follow-up). ORs were derived from binary logistic regression (outcome: responder yes/no; independent variable: group; adjustment: baseline upper limb radiating pain NRS); N is the number of participants with available NRS data at that time point; OR>1 indicates higher odds of responders in the HVP-PRF group.

Table 6: Cumulative acetaminophen dose over each follow-up interval.

Follow-up interval	Cumulative dose in HVP-PRF group (g)	Cumulative dose in C-PRF group (g)	Median difference	P
0-1 week after treatment	3.50 [2.75–4.5] (N=51)	3.25 [2.50–4.25] (N=50)	0.25	0.503
1 week-1 month after treatment	2.00 [1.00–2.50] (N=49)	2.50 [1.00–3.50] (N=48)	-0.50	0.087
1 month-3 months after treatment	1.00 [0.25–2.00] (N=48)	2.00 [0.50–3.00] (N=45)	-1.00	0.009
3 months-6 months after treatment	0.00 [0.00–0.50] (N=46)	1.00 [0.00–1.50] (N=44)	-1.00	0.013

Note: Data are presented as M[IQR]. P values were from the Mann-Whitney U test (two-sided); the difference is the median difference between the two groups (HVP-PRF - C-PRF). Rescue analgesia was acetaminophen (0.5 g per dose, maximum 2.0 g within 24 h).

Table 7: Adverse events and CTCAE grading.

Adverse event	HVP-PRF (n=51)	HVP-PRF (G1/G2/≥G3)	C-PRF (n=50)	C-PRF (G1/G2/≥G3)
Any adverse event	14 (27.45%)	11/2/1	16 (32.00%)	12/2/2
Serious adverse events	1 (1.96%)	0/0/1	2 (4.00%)	0/0/2
Puncture-site bleeding/hematoma	2 (3.92%)	2/0/0	2 (4.00%)	2/0/0
Puncture-site infection	0 (0.00%)	0/0/0	0 (0.00%)	0/0/0
Vasovagal reflex	1 (1.96%)	1/0/0	2 (4.00%)	2/0/0
Pain rebound within 48 h after the procedure	4 (7.84%)	3/1/0	5 (10.00%)	4/1/0
Persistent numbness or sensory abnormalities >7 d	3 (5.88%)	2/1/0	4 (8.00%)	3/1/0
New/worsened limb weakness	1 (1.96%)	0/0/1	1 (2.00%)	0/0/1
Dysphagia	1 (1.96%)	1/0/0	1 (2.00%)	1/0/0
Hoarseness	0 (0.00%)	0/0/0	1 (2.00%)	1/0/0
Dizziness	2 (3.92%)	2/0/0	3 (6.00%)	3/0/0
Pneumothorax	0 (0.00%)	0/0/0	0 (0.00%)	0/0/0
Vascular injury	0 (0.00%)	0/0/0	0 (0.00%)	0/0/0
Complications requiring hospitalization	1 (1.96%)	0/0/1	2 (4.00%)	0/0/2
Death	0 (0.00%)	0/0/0	0 (0.00%)	0/0/0

Note: CTCAE: Common terminology criteria for adverse events (v5.0); the same participant could have multiple adverse events. Based on the safety analysis set.

Safety outcomes

The incidence of adverse events was similar between the two groups (27.45% vs 32.00%), mainly G1–G2; serious adverse events were few (1.96% vs 4.00%), mainly complications requiring hospitalization and new/worsened limb weakness; no infection, pneumothorax, vascular injury, or death was observed (Table 7).

DISCUSSION

In this randomized controlled trial comparing HVP-PRF with C-PRF for elderly patients with cervical radiculopathy, we found that HVP-PRF provided superior pain relief at 3 months post-treatment, with the between-group difference exceeding the pre-specified minimal clinically important difference. The improvement in upper

limb radicular pain showed time dependence: The between-group difference was not apparent in the early period, but from mid-term follow-up onward, HVP-PRF achieved greater analgesic benefit that was maintained up to 6 months. Both multiple imputation and per-protocol analyses remained consistent in direction, suggesting the conclusion was robust. Among responders defined as a⩾ 50% pain decrease, the probability of achieving responder status was higher with HVP-PRF, and this efficacy advantage had clinically meaningful individual-level effects. It is important to distinguish between statistical and clinical significance in interpreting the current findings. The 3-month difference in radiating pain (adjusted mean difference [AMD] 1.24, 95% confidence interval [CI] 0.46–2.02) exceeded the prespecified MCID of 1.2 points, indicating clinically meaningful improvement. Similarly, the Neck Disability Index (NDI) difference at 3 months (AMD 6.47 points, 95% CI 2.11–10.83) approached the commonly cited MCID of 5–7 points for neck pain populations, suggesting clinically relevant functional benefit. However, the difference in neck pain at 3 months (AMD 0.79, 95% CI 0.18–1.40) was statistically significant but below the MCID and should be considered of limited clinical importance. This distinction reinforces the conclusion that the primary benefit of cervical nerve root pulsed radiofrequency is on radicular rather than axial pain a finding consistent with the anatomical rationale that nerve root modulation directly addresses radicular symptoms but has only indirect effects on axial neck pain arising from facet joints, myofascial structures and posture-related stress.

Intraoperative impedance and maximum needle-tip temperature were comparable between groups and did not exceed the upper temperature limit (42°C) in either group, supporting the conclusion that the observed difference was primarily attributable to electric-field effects rather than thermal destruction. The precise mechanisms by which pulsed radiofrequency exerts its analgesic effects remain incompletely understood. Proposed mechanisms include modulation of dorsal root ganglion excitability, inhibition of ectopic discharges and attenuation of neuroinflammatory responses (Occhigrossi *et al.*, 2026). The between-group difference observed is consistent with the hypothesis that increasing voltage under controlled temperature may enhance the electric field strength or volume of effect, but this interpretation remains speculative without direct neurophysiological or histological verification (Marquez *et al.*, 2026). This study did not measure biomarkers or perform neuroimaging to confirm these mechanisms and alternative explanations, including differential patient expectations or unmeasured procedural factors cannot be excluded. The gradual emergence of differences after 1 month post-treatment is more consistent with the cumulative biological effects of neuromodulation than with the immediate effects of short-acting drug injections.

The findings align with and extend the existing literature. A recent randomized trial by Alsaeid *et al*. (2025) demonstrated the superiority of high-voltage PRF over standard-voltage PRF in a broader adult population using fluoroscopic guidance. It further complements these findings by specifically focusing on the elderly population, a group with unique comorbidities and medication risks and by exclusively using ultrasound guidance with strict exclusion of perineural glucocorticoids and local anesthetics to isolate the pure neuromodulatory effect. Furthermore, 6-month follow-up data was provided on a wider range of secondary outcomes, including functional improvement (NDI) and rescue analgesia. Previous studies have mostly considered that PRF provides greater benefit for radicular pain than for axial pain and some studies suggest that parameter enhancement is associated with longer analgesic maintenance (Vuka *et al.*, 2020). However, other studies have found no obvious incremental benefit, often due to differences in target confirmation methods, parameter window settings and concomitant treatments (Chalermkitpanit *et al.*, 2023). In this study, ultrasound visualization combined with sensory and motor stimulation confirmation improved localization consistency and reduced the impact of mistargeting and differences in energy distribution, making the efficacy difference more likely attributable to parameter differences. Nevertheless, direct comparison with studies using fluoroscopic or CT guidance is limited by methodological heterogeneity and the optimal imaging modality for cervical PRF remains an area of ongoing investigation.

Between-group differences in functional outcomes were not prominent in the early period but gradually emerged after 1month post-treatment and peaked in mid-term follow-up, suggesting that control of radicular pain translated into recovery of daily activity capacity. Improvement in axial neck pain appeared later and with a smaller magnitude, indicating a limited direct contribution of nerve root modulation to axial pain. Axial neck pain is often driven by a combination of facet joint degeneration, myofascial load, and posture-related stress, and single-point nerve root modulation is unlikely to address the etiological chain fully; therefore, differences appear later and are smaller (Alaiti *et al.*, 2025). Patient Global Impression of Change was consistent with the direction of scale changes, with a higher proportion of marked improvement in mid-to-late follow-up and rare worsening, supporting that treatment benefits were perceptible to patients.

Rescue analgesic use was similar between groups in the early period but decreased after 1 month and remained lower, reflecting reduced medication demand due to improved pain control (Traistaru *et al.*, 2025). In the elderly population, reduced medication use helps mitigate the risk of adverse drug reactions. After relief of radicular pain,

protective postures and activity avoidance are reduced, upper limb use and neck-shoulder range of motion gradually recover and neuromuscular reflex tension decreases; improvement in functional scales often lags behind changes in pain (Traistaru *et al.*, 2025). Axial neck pain is often driven by a combination of facet joint degeneration, myofascial load, and posture-related stress, and single-point nerve root modulation is unlikely to address the etiological chain fully; therefore, differences appear later and are smaller (Haider & Gargya, 2023). Previous PRF studies have mostly reported that improvement in radicular pain precedes functional benefits and patient satisfaction and reductions in analgesic medication are often more evident at mid-term follow-up; the observed temporal pattern is consistent with this (Marliana *et al.*, 2021). The literature reports large differences in efficacy for axial neck pain, suggesting that combined management of other pain sources may be needed. Sustained benefits were obtained under the condition of not using perineural glucocorticoids and local anesthetics around the nerve root, further supporting that high-voltage parameters enhance neuromodulation effects within the temperature control framework rather than through short-acting drug effects (Conger *et al.*, 2024).

The intraoperative distribution of target segments and target confirmation indicators remained consistent between groups. Sensory stimulation thresholds were similar and motor stimulation did not induce visible muscle twitching in either group. Impedance and needle-tip temperature curves were within the same range, and treatment was completed within the prespecified upper temperature limit, indicating reliable localization and comparable energy delivery; the efficacy difference was more likely attributable to the electric-field effects of the voltage parameters rather than operational bias or thermal injury.

In terms of safety, the adverse event profiles were similar between groups, mainly mild-to-moderate transient reactions, with rare serious events and no infections, pneumothorax, vascular injuries, or deaths were observed, supporting that under the framework of ultrasound visualization and electrical stimulation confirmation, the high-voltage protocol did not lead to an observable increase in risk. PRF is primarily based on electric field modulation and temperature feedback limits heat accumulation, making increased voltage more reflected as enhanced electric field strength and range of action rather than tissue coagulation (Nishioka *et al.*, 2025). Ultrasound combined with Doppler can identify and avoid high-risk structures such as the vertebral artery; the in-plane approach reduces the risk of inadvertent intravascular entry and pleura-related complications; and sensory and motor stimulation further reduces the probability of inadvertent injury to motor fibers (Rusu *et al.*, 2025; Khan, Li*, et al.*, 2026). Although overall safety was acceptable, individual cases requiring hospitalization or with neurological changes still occurred, suggesting that postoperative neurological examination and follow-up should be strengthened in the elderly population, and that timely referral should be made when symptoms progress (Nilsson *et al.*, 2025). Previous studies generally consider that ultrasound guidance can improve the safety of cervical interventions and that PRF has a low complication rate; the feasibility of high-intensity parameters depends on temperature control and standardized target confirmation and requires attention to a small number of neurological function events; this safety profile is consistent with existing reports (Alsaeid *et al.*, 2025).

Strengths of this study include the randomized controlled design with allocation concealment and assessor blinding, the homogeneous elderly population, the standardized procedural protocol with rigorous target confirmation, the exclusive use of ultrasound guidance to avoid perineural injections and isolate the neuromodulatory effect, and the comprehensive 6-month follow-up with multiple clinically relevant outcomes. The consistency of results across intention-to-treat, multiple imputation, and per-protocol analyses supports the robustness of the primary conclusion. Including rescue analgesic use as an outcome provides real-world evidence of clinical benefit beyond differences in pain scales.

Limitations

This study has several limitations that should be considered. First, this was a single-center study with follow-up up to 6 months. The sample came from the same department and two experienced operators, with high procedural consistency, but limited external generalizability and whether efficacy can be maintained beyond 6 months remains uncertain. Second, the study population was limited to elderly patients with cervical radiculopathy and excluded those with cervical myelopathy and those requiring emergency surgery, thereby limiting the scope for extrapolating the conclusions. Third, interventional operators could not be blinded and participants may have formed expectations; although assessor blinding and allocation concealment were implemented, reporting bias could not be completely excluded. The potential for expectation and placebo effects due to lack of participant blinding is a notable limitation. Fourth, some follow-ups were completed by telephone, PGIC was presented descriptively only and secondary outcomes were not adjusted for multiple comparisons, so interpretation of supportive evidence should be cautious. Fifth, the sample size was estimated based on the primary outcome and the power to detect secondary outcomes and safety events was limited. Sixth, linear mixed-effects models rely on the missing-at-random assumption; although imputation and per-protocol analyses were consistent, the missingness mechanism may still affect estimates. Seventh, concomitant medications may have been adjusted due to comorbidities, medication records

relied on self-reporting and rescue analgesic amounts had measurement error. Eighth, the comparison covered only two voltage parameter levels and cannot yet answer the optimal voltage window and dose-response relationship. Finally, the deliberate exclusion of perineural glucocorticoids and local anesthetics, while methodologically advantageous for isolating the PRF effect, differs from some common clinical practices and may affect comparability with studies that permitted perineural injections. Future studies should conduct multicenter, extended follow-up parameter-gradient research, prespecify hierarchical endpoints, use inferential models for ordered outcomes, and combine electronic medication records and objective neurological function indicators to strengthen mechanistic evidence.

CONCLUSION

In this single-center randomized trial, ultrasound-guided high-voltage pulsed radiofrequency (70 V) provided greater relief of upper-limb radiating pain than conventional pulsed radiofrequency (45 V) at 3 months post-treatment in elderly patients with cervical radiculopathy, with the difference exceeding the minimal clinically important difference. The efficacy advantage was maintained through 6 months, although durability beyond this period cannot be determined from this study. Improvements in function, global impression of change and responder rates were directionally consistent and reduced rescue analgesic use in the HVP-PRF group during mid-to-late follow-up suggests practical benefit at the level of medication utilization. The adverse event profile was similar between groups, predominantly mild-to-moderate transient reactions. However, these safety findings should be interpreted with caution, as the study was powered for the primary efficacy outcome and lacks sufficient statistical power to exclude differences in rare or serious adverse events.

Furthermore, the single-center design, lack of participant blinding and limited external generalizability warrant consideration in interpreting the results. These findings support the potential utility of high-voltage PRF as an option for elderly patients with cervical radiculopathy. Still, confirmation in larger, multicenter trials with extended follow-up is needed.

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Author's contributions
Tingyang Dou: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. Zhenhua Zeng: Investigation, Data curation, Visualization, Writing – review & editing. Sanbao Zou: Investigation, Methodology, Resources. Shuo Deng: Investigation, Data curation. Feng Wei: Investigation, Software. Shaodong Xue: Investigation, Validation. Lulu Zhang: Conceptualization, Supervision, Project administration, Writing – review & editing. All authors read and approved the final manuscript.

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Data availability statement
The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. Due to patient confidentiality and ethical restrictions, data are not publicly available.

Ethical approval
This study was conducted in accordance with the ethical standards of the institutional and national research committees and with the Declaration of Helsinki. The study protocol was approved by the Ethics Committee of the First People's Hospital of Jiashan County (Approval No. 20240305-08A). All participants provided written informed consent prior to enrollment.

Trial registration
The trial was registered with the China Clinical Trial Registration Center (Registration Number: ChiCTR2400082698). This study was performed in adherence with the CONSORT guidelines. See supplementary file for the CONSORT checklist.

Conflict of interest
The authors declare that they have no competing interests, financial or non-financial, that could have appeared to influence the work reported in this paper.

Supplementary data
https://pjps.pk/uploads/2026/08/SUP1787570423.pdf

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